...ICAL
...ARY

THIS NUMBER COMPLETES VOLUME XXI

Volume XXI June, 1926 Number 6

SOIL SCIENCE

Editor-in-Chief
JACOB G. LIPMAN

Assistant Editors
CARL R. WOODWARD
HERMINIE R. BROEDEL

Contents

The Moisture Equivalent of Soils. Moyer D. Thomas and Karl Harris.. 411
The Influence of Lime and Phosphatic Fertilizers on the Phosphorus Content of the Soil Solution and of Soil Extracts. F. W. Parker and J. W. Tidmore..... 425
Synthetic Calcium Silicates as a Source of Agricultural Lime: II. A Comparison of Their Influence with That of Other Forms of Lime Upon Certain Microbiological Activities in the Soil. R. Marlin Barnette..... 443
Contribution to the Theory of the Origin of Alkali Soils. Alexius A. J. de'Sigmond..... 455
Do Colloids Exist as a Coating Around the Soil Grains. George John Bouyoucos..... 481
Relation of Fineness of Grinding to Rate of Sulfur-Oxidation in Soils. R. E. Stephenson..... 489
Index..... 495

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
Baltimore, Maryland, U.S.A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

EDITORIAL BOARD

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.
PROF. K. ASO
Imperial University, Tokyo, Japan
PROF. C. BARTHEL
Centralanstalten för Försöksväsendet på Jordbruksområdet, Stockholm, Sweden
PROF. A. W. BLAIR
Rutgers College, New Brunswick, N. J.
DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa
ALBERT BRUNO
Ministry of Agriculture, Paris, France
DR. H. R. CHRISTENSEN
Statens Planteavls-Laboratorium, Lyngby, Denmark
DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.
PROF. DR. H. VON FEILITZEN
Centralanstalten för Försöksväsendet på Jordbruksområdet, Stockholm, Sweden
DR. E. B. FRED
University of Wisconsin, Madison, Wis.
DR. J. E. GREAVES
Utah Agricultural College, Logan, Utah
DIRECTOR ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium
DR. R. GREIG-SMITH
Linnean Society, Sydney, New South Wales
DR. B. L. HARTWELL
Rhode Island Experiment Station, Kingston, R. I.
DR. D. J. HISSINK
Agricultural Experiment Station, Groningen, Holland
DR. C. B. LIPMAN
University of California, Berkeley, Calif.
DR. BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.
DR. F. LÖHNIS
University of Leipzig, Germany
DR. T. L. LYON
Cornell University, Ithaca, N. Y.
DR. M. M. MCCOOL
Michigan Agricultural College, East Lansing, Mich.
DR. W. H. MACINTIRE
Tennessee Experiment Station, Knoxville, Tenn.
DR. E. A. MITSCHERLICH
University of Königsberg, Prussia
PROF. C. A. MOOERS
Tennessee Experiment Station, Knoxville, Tenn.
DR. THEO. REMY
Institut für Boden- und Pflanzenbaulehre. Bonn a. Rh.
PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy
DR. E. J. RUSSELL
Rothamsted Experimental Station, Harpenden, England
DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.
DR. ALEXIUS A. J. DE'SIGMOND
Royal Joseph University of Technology, Budapest, Hungary
PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio
PROF. N. M. TULAIKOV
Agricultural Experiment Station, Saratov, Russia

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879
Copyright, 1926, by The Williams & Wilkins Company

ERRATA

SOIL SCIENCE, VOL. 21

"The viability of the nodule bacteria of legumes outside of the plant: I, II"

Page 51, line 3, paragraph 1 of summary, "*variable*" should read "*viable.*"

"A comparative study of the bacterial flora of wind-blown soil: I. Arroyo Bank Soil, Tucson, Arizona"

Page 146, table 3, column 7, heading "*water*" should read "*combustible material.*"

Page 147, footnote * table 5, should read "$\frac{\textit{water content}}{\textit{water capacity}} \times 100$."

"Do colloids exist as a coating around the soil grains"

Page 487, reference 5, *Josph* should read *Joseph.*

THE MOISTURE EQUIVALENT OF SOILS

MOYER D. THOMAS AND KARL HARRIS

Utah Agricultural Experiment Station

Received for publication November 12, 1925

A review of the literature on the Briggs-McLane method of determining the "moisture equivalent" of soils causes serious doubt as to the general correctness of those authors' original idea, that in this process "each soil loses water until the capillary forces have been increased sufficiently to balance the centrifugal force acting on the soil moisture" (3, p. 140) and that this so-called constant is "a single valued numerical expression of the moisture retentiveness of the soil measured in a definite way which establishes at once a relationship between this soil and any other soil whose moisture equivalent is known" (3, p. 145). Without denying the wide utility of the method for the purpose as outlined by Briggs and McLane, it is our intention in this paper to discuss the theoretical aspects and point out some limitations of the method.

It is significant to note that the numerous attempts (2, 7, 10) to correlate mechanical composition with the moisture equivalent have not been particularly successful. This may be due in part to the fact that the ordinary method of mechanical analysis does not give sufficient information about the clay fraction, but other factors are obviously involved as well. Indeed, the incentive for the present investigation was the observation that the finest textured horizon of a heavy clay profile gave the lowest moisture equivalent.

Middleton's data (7, p. 160) indicate that on the average, silt loam and silty clay-loam may retain nearly as much water in the moisture-equivalent machine as clay and considerably more than sandy clay, loam, or clay-loam, which are about equal in this respect. Evidently, the silt has an important water-retaining power. In the various equations for calculating the moisture-equivalent from the mechanical analysis the ratios of the coefficients of the silt and clay are as follows: Briggs and McLane, 0.2; Alway and Russel (1) 0.5; Middleton (equation 2), 0.68.

It is recognized that the soil structure may have a profound effect on the moisture-equivalent. Sharp and Waynick (9) have increased this value 50 per cent in the case of a clay-loam soil by treating with a normal solution of a sodium salt and subsequently washing with water. Calcium chloride was without effect. It is well known that the treatment with sodium salts as carried out by these authors produces an alkaline soil which has a "bad" physical condition and is very impermeable to water. Joseph and Hancock (5) propose the use of the moisture-equivalent method to determine the plasticity

of clay by making determinations under ordinary conditions and also after ignition as well as after saturating the unignited material with 3 per cent sodium carbonate instead of pure water.

It is evident therefore that, particularly in the case of fine-textured soils, the moisture-equivalent may be influenced to a greater extent by the arrangement and state of aggregation of the particles than by their size and distribution of size. It is evident also that the permeability of the sample is often an important factor which may preclude the attainment of a capillary equilibrium in any reasonable length of time. If a capillary equilibrium is not attained, the determination is without quantitative significance, though it may indicate qualitatively the impermeable nature of the material. This is an argument against the practice of arbitrarily making the time of centrifuging the same for all kinds of soil.

The senior author (11) has already proposed a partial solution of the problem of the capillary equilibrium by equating the "centrifugal" force to the capillary potential gradient. The question has been studied further by Veihmeyer and his coworkers (13) who have considered in detail the distribution of the moisture and the apparent specific gravity of the soil block. Russel and Burr (8) have recently determined the water retained when the speed of the machine is varied to correspond to forces ranging from 100 to 1400 times gravity. More information is now needed on the influence of the outer boundary and also on the relation between the size of the soil particles and the distribution of the water in the soil mass. Data on these questions are submitted in this paper.

EXPERIMENTAL

In the work reported below a standard machine was used which operated at 2410 to 2430 r.p.m. The following soils were studied:

T1. A very heavy calcareous Trenton clay.
G1. A fertile silty clay-loam from the Greenville Farm.
1170. Ballard Clay (0–11 inches)—a light clay nearly free from lime.
1170A. A separate from 1170 with all particles smaller than 2μ in diameter.
1171. Ballard Clay (11–15 inches)—a very heavy clay containing 2 per cent calcium carbonate, subsoil to 1170.
1286. Ramona clay-loam from La Habra, California, supplied by W. P. Kelley. This sample has been extensively studied by Dr. Kelley as Soil 431.
Separates from *G1* as follows: S.W. 5; S.W. 6; S.W. 7; and S.W. 9.
Separates from *T1* as follows: T0, T2, T3, T4, T5, T6, and T7. Also a mixture of T0 and T2.

The size-distribution curves of the first two soils and most of the separates have already been published (12, p. 5).

Amount of material centrifuged

It has been shown (8, 11, 13) that the percentage of water retained by a soil decreases as the amount of soil centrifuged increases, except in the case of

TABLE 1

Influence of the size of sample and time of centrifuging on the moisture-equivalent of the soil separates

SOIL NUMBER	SIZE LIMITS DIAMETER	WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT		WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT	
	μ	*gm.*	*hours*	*per cent*	*per cent*	*gm.*	*hours*	*per cent*	*per cent*
S.W.5	40–90	25.0	1.0	5.4	4.1	60	1.0	3.7	....
S.W.6	30–80	26.0	1.0	7.0	8.0	..	...	....	....
S.W.7	28–60	26.0	1.0	8.6	8.6	..	..	....	....
S.W.9	16–40	5.0	1.0	32.3	32.1	31	1.0	10.1	11.4
		10.0	1.0	26.7	27.4	35	3.5	10.2	12.3
		20.0	1.0	15.4	16.6	40	1.0	10.1	9.8
		25.0	1.0	12.4	16.1	70	2.0	6.9	7.5
		25.0	2.0	13.3	....	70	3.5	5.5	8.1
T0	12–22	17.5	2.0	37.3	....	..	...	....	....
T0 + T2	5–22	5.0	2.0	44.7	41.8	25	3.5	32.4	....
		10.0	0.5	46.1	46.3	..	...	....	....
T2	5–12	10.0	0.5	40.2	40.7	25	3.5	36.2	....
		25.0	2.0	34.4	....	..	...	....	....
T3	4.4– 9	5.0	0.5	35.0	34.0	25	2.0	33.2	32.6
		10.0	0.5	32.8	34.2	40	3.5	31.2	30.2
T4	2– 5	5.0	0.5	38.7	38.6	24	2.0	39.7	39.6
		5.0	1.0	38.4	39.4	24	3.5	38.1	37.3
		5.0	3.0	39.1	38.1	35	2.0	38.3	38.5
		10.0	0.5	39.0	37.9	35	8.7	36.2	36.6
		10.0	2.0	37.8	38.1	50	2.0	37.6	37.1
		17.0	2.0	38.5	....	50	8.7	34.6	37.1
T5	1– 3	5.0	0.5	42.8	42.3	10	3.5	42.7	40.1
		5.0	1.0	41.5	42.3	20	2.0	43.8	44.4
		5.0	2.0	41.6	43.4	20	3.5	41.6	41.0
		10.0	0.5	43.1	43.5	30	3.5	40.3	41.0
		10.0	1.0	43.7	42.3	50	2.0	42.5	42.8
		10.0	2.0	43.4	43.8	50	8.7	40.6	40.6
T6	Smaller than 1.0	25.0	2.0	50.1	49.5	..	...	....	....
T7	Smaller than 0.5	25.0	2.0	60.4	61.3	..	...	....	....

impermeable materials, which do not permit the ready passage of water through the larger samples. These observations are confirmed by the data presented in tables 1 and 2, which show the influence of the amount of sample and the time of centrifuging on the water retained by the soil separates and by the Trenton clay respectively. It will be seen that the amount of material centrifuged has a marked effect in the case of separate S.W.9, but a very slight effect on the finer silts, T4 and T5, and also on the coarser separate S.W.5. When the size of the sample is increased, Trenton clay shows first a decrease then an increase in the amount of water retained after two hours, but a longer period in the centrifuge reduces the water content of the larger blocks to about 28 per cent. It was observed that the samples which were drier than 28 per cent contained radial cracks due to shrinkage and this final reduction of the moisture content was therefore accomplished by evaporation,

TABLE 2

Influence of size of sample and time of centrifuging on the moisture-equivalent of Trenton Clay

WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT		WEIGHT OF SAMPLE	TIME	MOISTURE EQUIVALENT	
gm.	*hours*	*per cent*	*per cent*	*gm.*	*hours*	*per cent*	*per cent*
5	2.0	35.9	37.3	40	2.0	31.0	32.6
10	2.0	36.3	36.7	40	8.7	30.4	30.3
20	2.0	33.2	31.4	50	2.0	34.4	34.8
25	0.7	38.8	40.0	50	8.7	29.6	29.8
25	8.7	29.5	32.5	60	2.0	35.2	35.6
30	2.0	31.6	32.6	60	8.7	30.9	30.1
30	18.0	30.0	17.0*	60	18.5	25.8†	28.2
30	25.5	22.7*	25.5†	60	37.5	19.0*	27.6†
30	29.0	10.3*	....	60	48.5	19.3*	26.3†
30	40.0	26.3†	13.2*	60	54.5	17.0*	25.1*

* Large radial cracks had formed in the soil block and at least some sections of the block were nearly air-dry.

† Large radial cracks had formed in the soil block.

since air could then pass freely through the block of soil. This was indicated by the fact that frequently one detached portion of the soil block was nearly air-dry when other parts were very moist. Moreover, duplicate determinations varied widely in these drier samples, showing that the permeability to air was variable.

When the moisture equivalent of a definite amount of each soil separate is plotted against the average diameter (using a logarithmic size scale for convenience), a curve is obtained with a maximum at about 10μ and a minimum at about 5μ. (Fig. 1.) This effect is more noticeable in the 10-gm. samples than in the 25-gm. samples. It seems likely that the maximum represents a condition in which the pores are just small enought to remain completely filled with water, and in which the packing of the solid particles is less dense than in the case of the finer separates. Increasing the amount of material centrifuged

would then tend to obliterate the maximum because of the establishment of a moisture gradient in the soil as well as of closer packing.

Distribution of the Water

From theoretical considerations, it seems evident that the criterion for an equilibrium in which capillary forces balance the centrifugal force of the machine, is a decrease in the water content of the soil in the direction of the axis of rotation. This gradient is a function of the texture and manner of packing of the soil materials. It should be small in coarse sands, because the capillaries are so large that the centrifuge can easily throw out most of the water and we are dealing only with small water wedges at the points of con-

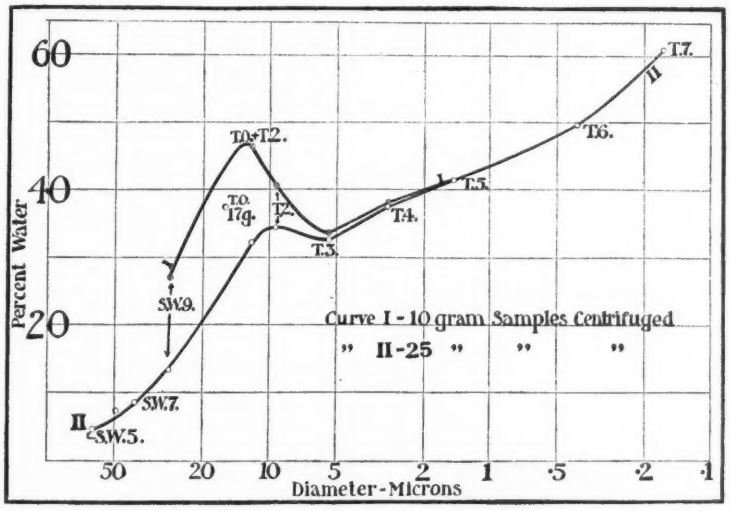


FIG. 1. MOISTURE RETAINED BY THE SOIL SEPARATES

The abscissa represents the average size of the particles of each separate, on a logarithmic scale.

tact of the solid particles. On the other hand, the largest capillary spaces of very fine textured soils may be so small that the centrifuge is unable to empty them and in this case there will be a nearly uniform distribution of the moisture at equilibrium. Between these extremes, it should be possible to realize a large gradient.

The moisture distribution in the centrifuged soil mass was found by cutting the block into several pieces, perpendicular to the radius of the machine, and drying each portion separately. This division in some cases was made roughly by means of a spatula; in others, exactly by the use of the slicing device described by Veihmeyer et al (13, p. 19–24).[1]

[1] This apparatus was very kindly lent to us by Prof. Frank Adams, University of California.

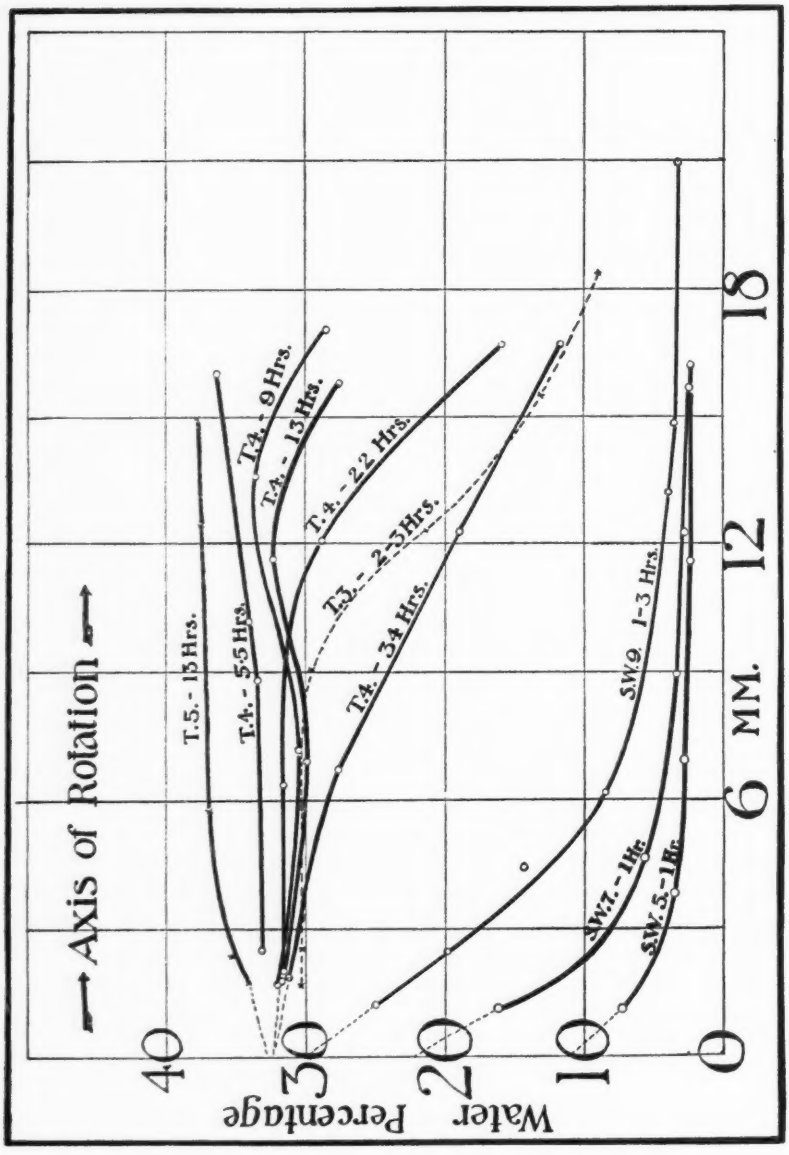


FIG. 2. DISTRIBUTION OF WATER IN THE SOIL SEPARATES AFTER CENTRIFUGING FOR DIFFERENT LENGTHS OF TIME AS INDICATED ON THE CURVES

The abscissa represents the distance from the outside boundary

The data for the soil separates are presented graphically in figure 2, and the results for Trenton clay are given in table 3. These data show:

(*a*) That the moisture gradient in soil S.W.5 is small.

(*b*) That a large moisture gradient is readily established in soil S.W.9; and that soil T3 behaves similarly but less readily.

(*c*) That the movement of water through soil T4 and soil T5 is so slow that it requires many hours for the excess of water to move from the inner surface to the outside boundary and establish a moisture gradient opposing the centrifugal force of the machine. The series of curves representing soil T4 depict this movement clearly; and a similar series might be drawn for soil T5. It should be emphasized that in these cases considerable difficulty would be encountered in arriving quantitatively at equilibrium because of the possibility of some evaporation taking place from the inside layers during the long exposure in the centrifuge.

TABLE 3

Distribution of the water in 60-gm. samples of Trenton clay

The blocks of soil were cut perpendicular to the radius of the machine. The first value represents the portion nearest the outside boundary.

TIME	THICKNESS OF SECTION	WEIGHT OF SECTION	WATER	TIME	THICKNESS OF SECTION	WEIGHT OF SECTION	WATER
hours	*mm.*	*gm.*	*per cent*	*hours*	*mm.*	*gm.*	*per cent*
2.0	....	15.7	30.8	8.7	3.75	12.6	28.3
	3.0	9.5	31.5		3.0	10.1	27.8
	3.0	9.7	32.7		3.0	10.1	28.2
	3.0	9.9	34.2		3.0	8.9	28.0
	....	12.3	37.2		3.0	9.6	28.0
	....	....	....		....	7.0	28.5
18.5	....	10.1	24.4	18.5	....	13.2	28.6
	....	18.2	25.9		....	17.3	28.1
	....	18.1	26.2		....	15.8	28.2
	....	13.0	25.9		....	14.0	27.9
54.5	....	26.7	16.9	54.5	....	16.2	25.5
	....	14.7	16.9		....	22.5	25.1
	....	10.8	17.3		....	10.1	25.0
	....	7.6	17.0		....	11.5	24.9

(*d*) Trenton clay has an increasing moisture content toward the axis of rotation until it has been centrifuged long enough to establish a uniform distribution at about 28 per cent of water. Subsequent drying, due to cracking and evaporation, does not alter this uniform distribution.

(*e*) With the fine textured soils, many hours of centrifuging are required approximately to establish equilibrium.

The influence of texture on the moisture distribution, as described above, can be inferred from the results of Russel and Burr (8). When these authors plotted the amount of moisture, M, retained against the centrifugal force, G,

The abscissa represents the distance from the outside boundary

they obtained a family of curves, parabolic in form, which could be expressed by the equation:

$$M = \frac{K}{G^n}$$

where K and n are constants which decrease in value (except for the coarsest material) as the texture becomes finer. As the value of n determines the shape of the curves, it is clear that as the texture becomes finer (except for the coarsest sand) there will be a decrease in the influence of changing the speed of the machine on the amount of water retained.

It may be pointed out that the moisture gradient as found in the centrifugal machine should be one thousand times as great as in the gravitational field. Useful information could readily be obtained from capillary potential studies if the equilibrium moisture gradient under field conditions could be calculated from moisture equivalent data. Data are available for this comparison in the case of the Greenville soil. From figure 3 it may be estimated that the moisture gradient of this soil (containing about 18 per cent of water) under the influence of gravity should be 0.08 per cent per foot. Israelsen (4, fig. 15) has actually found by a study of this soil in the field a value of 0.14 per cent per foot in the case of the uniform-textured upper 4 feet of plat B (4, fig. 13). In this work, field plats were given heavy irrigations, then covered with straw to prevent evaporation, and sampled at intervals for several months until equilibrium was reached. This agreement is fairly good in view of the fact that the two cases are probably not strictly comparable, because of differences in packing. The gradient, as determined for all the data in his figure 15, is 0.35 per cent per foot, but as these data involve a correction for texture which is admittedly an approximation it seems best to make the above comparison on the basis of uniform-textured soil.

The apparent specific gravity

Veihmeyer and coworkers (12) have determined the apparent specific gravity of their soils after centrifuging. They show that the compaction increases somewhat with increasing weight of soil used, and that within a 60-gm. sample the apparent density increases for about 6 mm. from the inside surface, beyond which it remains nearly constant. We have made a few calculations of the apparent specific gravity of our soils from data obtained by the slice-weight method (13, p. 24). The values presented in table 4 are the averages of several determinations in most cases. The paraffin method was unsatisfactory because there was a tendency for the hydrocarbon to penetrate the soil.

It will be seen that the Trenton separates are less compact than the other soils and also that their pores are nearly completely filled with water. An explanation is thus afforded for the high water retaining power of the fine silts as compared with heavy clay: the capillary spaces which the centrifuge is

unable to empty are occupied entirely with water in the silt whereas part of the corresponding space in the clay is occupied by colloidal particles.

The outside boundary

Considerable theoretical interest is attached to the outside boundary. If the moisture percentage at this point is varied, changes should be reflected throughout the remainder of the soil mass. The capillary potential gradient should remain unchanged but the moisture gradient should probably decrease as the outside surface becomes drier. This follows from the fact that the capillary potential-moisture curve for soil appears to be a rectangular hyperbola (11).

The question was studied experimentally as follows:

A number of different kinds of filter paper boundaries were first tried using Greenville soil. No significant changes in the moisture equivalent were observed. Boundaries were next constructed using 5-gm. samples (1.6 mm. thick) of the different soil separates. These were retained in the cup and also by means of two filter papers were separated from the 60-gm. samples of Greenville soil placed on top. Four periods of centrifuging were employed: 2, 5½, 7, and 16 hours. The soil was dried in layers.

TABLE 4

Degree of packing and water retaining power of the soils

SOIL NUMBER	WEIGHT OF SOIL USED	SPECIFIC GRAVITY		WATER RETAINED BY		WATER REQUIRED TO FILL PORE SPACE
		Real	Apparent	Entire soil mass	Outer layer	
	gm.			*per cent*	*per cent*	*per cent*
S.W.5	60	2.72	1.40	3.7	8.4	34.6
S.W.9	60	2.72	1.40	9.5	32.3	34.6
T3	60	2.72	1.28	23.0	30.8	40.1
T4	60	2.72	1.32	32.0	33.0	39.0
T5	60	2.72	1.36	35.7	36.5	36.7
G1	60	2.75	1.46	18.3	21.3	32.0
T1	60	2.77	1.40	28.1	28.5	35.3

The two intermediate periods gave closely agreeing results; but two hours was not sufficient to establish equilibrium and 16 hours seemed to permit some evaporation. The data presented in figure 3 are the averages of the two intermediate periods and show the distribution of the water in the Greenville soil when the boundary material was that indicated on the curve. It will be seen that soil S.W.9 increases the amount of water retained by the Greenville soil above that shown by one piece of filter paper, whereas the Trenton separates cause a decrease which is greater the finer the separate. The sandy separate S.W.5 also causes a decrease and behaves in an anomalous fashion. The other curves are all nearly parallel and seem to indicate that the gradient is nearly constant over this range, the position of the curve depending on the outside boundary. However, the moisture gradient in the wetter soils is some-

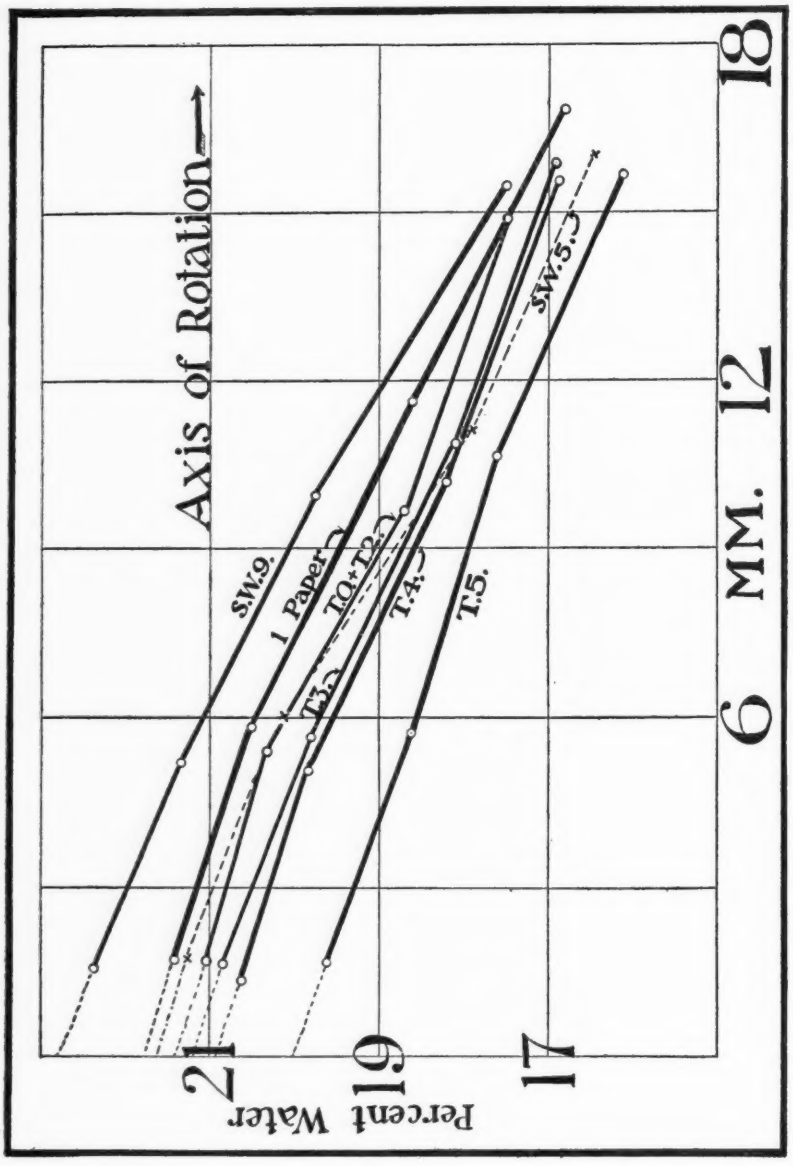


FIG. 3. DISTRIBUTION OF WATER IN THE GREENVILLE SOIL (G1) AFTER CENTRIFUGING 5.5 TO 7 HOURS, USING OUTSIDE BOUNDARY MATERIALS AS INDICATED IN THE CURVES

The abscissa represents the distance from the outside boundary

what greater than in the drier soils. It is suggested that the water in the outer layers of the Greenville soils is in capillary equilibrium with the water in the separate which acts as a boundary, and therefore, the negative curvature of the water wedges in the soil will be increased, with a corresponding decrease in the moisture content, as the size of the capillaries in the outer surface is reduced. No attempt is made to explain the behavior of S.W.5, further than to state that after 2 hours centrifuging, this material gave a distribution identical with that shown in figure 3 for S.W.9.

These data can be studied quantitatively through the following thermodynamic relations:

$$ln \frac{P_0}{P_1} = \frac{Mgh}{RT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A)$$

$$ln \frac{P_0}{P_1} = \frac{M}{RT} \frac{2t}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (B)$$

In these equations P_1 is the vapor pressure at height h above a flat water surface of vapor pressure P_0, in equilibrium with a water surface having a negative radius of curvature r, and t is the surface tension of water. The vapor pressure lowering in the gravitational field g at constant temperature, according to equation A, is 0.0072 per cent per meter of elevation above a flat water surface. In the centrifugal field of the moisture equivalent machine, this value is 0.0072 per cent per millimeter, at least over a small range, in the direction of the axis of rotation. Equations connecting the vapor pressure and capillary potential functions have already been published (11).

In figure 3, it may be seen that the outside layer of the Greenville soil having T5 as the boundary material has the same moisture content as the layer 9 mm. within the soil mass when S.W.9 is the boundary material. The outside layer of the former sample of Greenville soil should therefore have a vapor pressure 0.065 per cent lower than the outside layer of the latter. It remains now to determine whether this difference can be accounted for by the difference in size of the capillary spaces of the two separates. Since the pore space of both T5 and S.W.9 is about 50 per cent (table 4) the average size of the capillary spaces in each case is probably equal to the average size of the soil particles, viz., 0.9 and 13μ radius. If we substitute these values of r in equation B, we obtain vapor pressure lowerings of 0.116 per cent and 0.008 per cent respectively. The value of r which corresponds to a vapor pressure lowering of 0.065 per cent + 0.008 per cent[2] is 1.4μ.

Table 5 shows the results of this calculation for the data of figure 3. The soil separates were practically saturated with water in each case.

The agreement of the vapor pressure values calculated by the two independent methods is satisfactory, considering the uncertainty connected with the

[2] This addition of 0.008 per cent is made because the calculation is referred to the capillaries of soil S.W.9 instead of to a flat-water surface.

The abscissa represents the distance from the outside boundary

evalution of the size of the capillary spaces, and shows quantitative conformation to the theory of capillary equilibrium.

Base replacement

Five clay soils, three of which were highly colloidal, were treated repeatedly with normal solutions of the chlorides of ammonium, sodium, potassium, calcium, and aluminum, as well as 0.05 *N* hydrochloric acid, and subsequently

TABLE 5

Influence of the size of the capillary spaces in the boundary material on the vapor pressure of the adjacent layer of the Greenville soil

BOUNDARY MATERIAL				ADJACENT LAYER GREENVILLE SOIL	
				Vapor pressure lowering	
Number	Size limits radius-microns by mechanical analysis	Average size of particles (or pores) radius-microns	Size of pores calculated from vapor pressure data (column a) radius-microns	From equation A (+ 0.008) a	From equation B b
				per cent	*per cent*
S.W.9	8–20	13.0	(13.0)	(0.008)	0.008
T0 + T2	2.5–11	5.0	3.0	0.038	0.021
T3	2.2–4.5	3.0	2.6	0.042	0.035
T4	1.0–2.5	1.6	1.9	0.057	0.065
T5	0.5–1.5	0.9	1.4	0.073	0.116

TABLE 6

Influence on the moisture-equivalent of treating the soil with various solutions and subsequently washing out the soluble material

Time of centrifuging—45 minutes; weight of sample—20 gm.

SOIL NUMBER	MOISTURE EQUIVALENT AFTER TREATMENT							
	Natural soil	Washed with H_2O	*N* $AlCl_3$	*N* $CaCl_2$	0.05 *N* HCl	*N* KCl	*N* NH_4Cl	*N* NaCl
1170	32.9	32.5	....	36.0	34.1	35.1	34.6	40.6
1170A	....	53.3	50.7	53.7	51.2	65.9	67.6	75.5
1171	42.0	51.7	....	47.7	47.9	50.0	50.8	69.2
1286	34.4	....	37.4	38.5	36.5	37.7	39.5	82.7
T1	39.4	....	....	38.8	....	40.3	41.7	60.0

washed free of soluble material. The soil was then air-dried and moisture equivalent determinations were made on 20-gm. portions, centrifuging for 40 minutes. The results are given in table 6, which shows a marked increase of moisture retention as a result of the sodium treatment. The other bases behave nearly alike although ammonium and potassium have a slight tendency to increase the moisture retention. The low value obtained with the natural soil 1171 is probably due to the presence of 1 per cent of soluble salt

in the sample. The sodium-treated soils were very impermeable and some free water was usually present inside the cup. Sufficient material was not available for a detailed study of these effects. It is unlikely that equilibrium was attained in any case. The results are therefore a measure of the comparative permeability, as influenced by the degree of swelling of the colloids. Since soil colloids possess elastic properties the sodium-saturated compounds would probably be more swollen and retain more water at equilibrium than the others. This does not necessarily prove that its "internal surface is greater" as suggested by Sharp and Waynick (9). The data suggest the importance of a consideration of soil structure in comparing results obtained by the moisture equivalent method, particularly in the case of fine-textured soils.

SUMMARY

A study of the moisture equivalent method as it is influenced by the amount of material centrifuged; by the texture and chemical treatment of the soil; and by the nature of the outside boundary, leads to the following conclusions:

1. Increasing the size of sample reduces to a slight extent the amount of water retained in very coarse and very fine soils, whereas soils of intermediate texture show greater effects.

2. The moisture gradient in the soil mass, opposing the centrifugal force of the machine shows a similar maximum with intermediate textures. Very fine grained soils have a nearly uniform moisture distribution at equilibrium.

3. A period of many hours centrifuging is often required to establish capillary equilibrium in the case of heavy clays and very fine silts. The slow movement of water through a silt is shown graphically.

4. When 10- to 25-gm. samples are centrifuged, silt of about 10μ average diameter retains more water than silt of 5μ average diameter. This excess of water decreases with the increasing size of the sample.

5. The very fine silts have a lower apparent specific gravity than the heavy Trenton clay, and also retain as much or more water. It is suggested that the capillaries in the silt which the centrifuge is unable to empty are filled entirely with water, whereas in the clay the corresponding interstices contain some colloidal material.

6. As the capillaries of the outside boundary are reduced in size, the adjacent soil becomes drier and this reduction in the moisture content is reflected throughout the whole soil block. This effect conforms quantitatively to the thermodynamic theory of capillary equilibrium.

7. When the replaceable base of a clay is entirely sodium, the impermeability, and probably also the equilibrium moisture retaining power, are greater than when the replaceable base is potassium, ammonium, calcium, aluminum, or hydrogen. The colloidal swelling is enhanced by the sodium in the complex.

REFERENCES

(1) ALWAY, F. J., AND RUSSEL, J. C. 1916 Use of the moisture equivalent for the indirect determination of the hygroscopic coefficient. *Jour. Agr. Res.* 6: 833–846.

(2) BRIGGS, L. J., AND MCLANE, J. W. 1907 The moisture equivalent of soils U. S. Dept. Agr. Bur. Soils Bul. 45.

(3) BRIGGS, L. J., AND MCLANE, J. W. 1910 Moisture equivalent determinations and their applications. *Proc. Amer. Soc. Agron.* 2: 138–147.

(4) ISRAELSEN, O. W. 1926 The application of hydrodynamics to irrigation and drainage problems. *In press*, Univ. Cal.

(5) JOSEPH, A. F., AND HANCOCK, J. S. 1924 The composition and properties of clay. *Jour. Chem. Soc.* 125: 1888–1895.

(6) JOSEPH, A. F., AND MARTIN, F. J. 1923 The moisture equivalent of heavy soils. *Jour. Agr. Sci.* 13: 49–57.

(7) MIDDLETON, H. E. 1920 The moisture equivalent in relation to the mechanical analysis of soils. *Soil Sci.* 9: 159–167.

(8) RUSSEL, J. C., AND BURR, W. W. 1925 Studies on the moisture equivalent of soils. *Soil Sci.* 19: 251–266.

(9) SHARP, L. T., AND WAYNICK, D. D. 1917 The moisture equivalent determinations of salt treated soils and their relation to changes in the interior surfaces. *Soil Sci.* 4: 463–469.

(10) SMITH, A. 1917 Relation of the mechanical analysis to the moisture equivalent of soils. *Soil. Sci.* 4: 471–476.

(11) THOMAS, M. D. 1921 Aqueous vapor pressure of soils. *Soil Sci.* 11: 409–434.

(12) THOMAS, M. D. 1924 Aqueous vapor pressure of soils: II. *Soil Sci.* 17: 1–18.

(13) VEIHMEYER, F. J., ISRAELSEN, O. W., AND CONRAD, J. P. 1924 The moisture equivalent as influenced by the amount of soil used in its determination. Univ. Cal. Col. Agr. Tech. Paper 16.

THE INFLUENCE OF LIME AND PHOSPHATIC FERTILIZERS ON THE PHOSPHORUS CONTENT OF THE SOIL SOLUTION AND OF SOIL EXTRACTS[1]

F. W. PARKER AND J. W. TIDMORE

Alabama Agricultural Experiment Station

Received for publication November 16, 1925

The influence of lime on the solubility of phosphorus in the soil, both native and that added in different forms of phosphatic fertilizer, has been studied by a number of investigators. Ames and Schollenberger (1) have given a summary of the literature on the subject showing the varied results that have been secured by different workers. A study of these experiments indicates that in many instances the methods used were inadequate or not well adapted to the investigation, but in recent years new methods of soil investigation have been suggested that seem to be well adapted for use in a study of this problem.

In previous work the solubility of the soil phosphorus has been studied by means of extraction with dilute acid or water. Although such studies are valuable it seems very desirable to obtain data on the phosphorus content of the soil solution also. Recently Parker (13) and Burd and Martin (6) have made a study of the soil solution obtained by the displacement method. Their results show that the true soil solution is obtained by displacement. With the use of the procedure recommended by Burd and Martin sufficient soil solution for analysis can readily be obtained from most soils.

Preliminary studies showed that the phosphorus content of the soil solution was so low that the usual methods of determining phosphorus were of little value. A method for determining phosphorus in the soil solution should be very sensitive, capable of determining at least 0.05 p.p.m. PO_4 in the solution. Such a method has recently been used by Atkins (2) in the determination of phosphorus in soil extracts. A study of the method in this laboratory (14) shows that it is simple, rapid, and accurate. A very similar method has been used extensively by biological chemists (3). The method makes possible the determination of phosphorus in 100 cc. of solution containing only 0.02 p.p.m. PO_4. As it has many advantages over the older colorimetric method for determining phosphorus it was used in the present investigation.

It has been customary to prepare water extracts of soils by filtering them through Pasteur-Chamberland filters. Apparently in none of the work reported has a careful study been made of the influence of the filter on the phos-

[1] Published with the permission of the Director of the Alabama Agricultural Experiment Station.

phorus content of the soil extract. However, recent work in this laboratory (14) has shown that Pasteur-Chamberland filters absorb or give up phosphorus depending upon the relation between the degree of saturation of the filter and the phosphate concentration of the solution being filtered. Since the filter may materially alter the phosphate content of the solution it is probable that most of the data on the phosphorus content of soil extracts are of doubtful value. Consequently, the use of that method has been discontinued and another procedure adopted. In the present investigation all extracts were prepared by dialysis through collodion sacks. The detailed procedure will be given later.

Having the aforementioned methods in mind, the investigation was undertaken to determine the following: (*a*) the influence of lime on the phosphorus content of the soil solution and soil extracts from soils which have never received phosphatic fertilizer; (*b*) the influence of lime on the phosphorus content of the soil solution and soil extracts from soils fertilized with different phosphatic fertilizers; and (*c*) the influence of lime and different phosphatic fertilizers on the solubility of soil phosphorus. The solubility is indicated by a comparison of the concentration of phosphate in the soil solution and in soil extracts. The results also afford a comparison of the influence of different sources of phosphorus on the phosphate content of the soil solution and soil extracts. The sources of phosphorus studied include steamed bone meal, acid phosphate, rock phosphate, and basic slag.

METHODS

The soils used in this investigation were taken from experimental plots in Alabama, Ohio, Illinois, and Kentucky.[2] In all instances approximately twenty-five-pound samples of the surface soil were secured from each plot. On reaching the laboratory the soil was screened and placed in earthenware jars and brought to the moisture content considered most satisfactory for displacement—this varied from 10 per cent in the sandy soils to 25 per cent in one heavy soil. After their contents were mixed again the jars were covered to prevent evaporation until the soil solution was displaced.

The displacement procedure was essentially that used by Burd and Martin (6). A definite amount of soil at a known moisture content was packed in the displacement cylinders. Water was added and displacement was made under an air pressure of 15 to 20 pounds to the square inch. Successive 100- or 200-cc. portions of the displaced solution were obtained and used in subsequent work.

The first portion of the displaced solution is the true soil solution undiluted by the displacing liquid. In the second and successive portions the soil

[2] The authors wish to express their appreciation to Dr. F. C. Bauer for furnishing the samples from the Illinois plots, to Prof. A. W. Ames for furnishing the samples from the Ohio plots, and to Prof. George Roberts for furnishing the samples from the Kentucky plot.

solution becomes more and more diluted by the displacing liquid. This dilution is indicated by a gradual decrease in the calcium content and by an increase in the specific resistance of the successive portions. The specific resistance and the calcium and phosphorus were determined in the different portions.

The displaced solution was usually clear, but preliminary work showed that often a small amount of material was in suspension. As this material could not be removed satisfactorily by centrifuging, all solutions were dialyzed through a collodion membrane. A 100-cc. portion of the solution was placed in each of two collodion sacks. These were then placed in 250-cc. beakers containing 100 cc. of distilled water. Conductivity determinations indicated that equilibrium between the inside and the outside solutions was established in 18 hours; at the end of that time the specific resistance of the two solutions was the same. After the solution stood for 18 to 21 hours the collodion sacks and contents were removed, the two 100-cc. portions of diffusate were combined, 50 cc. was used for the determination of calcium and 150 cc. was used for the determination of phosphorus. The 150 cc. is equivalent to 75 cc. of the original solution.

Calcium was determined by titration of the oxalate with 0.05 *N* $KMnO_4$. In determining phosphorus in the soil solution, by the procedure recommended by Parker (14), the solution was evaporated, and the residue was ignited and taken up with acid. In the case of soil extracts the determination was made on 100 cc. of the extract without evaporating.

The 1:5 soil extracts were prepared by placing 40 gm. of soil in a 150-cc. collodion sack and adding 100 cc. of water to the soil. The sack was then placed in a 250-cc. beaker containing 100 cc. of water. The contents of the sack were shaken three times a day and were allowed to stand about 24 hours. At the end of that time the specific resistance of the inside and outside solutions was the same. Phosphorus was determined in the 100 cc. of solution in the beaker, called "outside solution" or "diffusate."

EXPERIMENTAL RESULTS

Cullar's Rotation Field, Auburn, Alabama

Since 1910 these plots have carried a 3-year rotation of cotton, corn, and oats followed by cowpeas. Lime was applied to one-half of all plots in 1915 at the rate of 2 tons of ground limestone to the acre. The soil is Norfolk sandy loam, slightly acid to the Truog test.

The plots used in this study were carefully sampled June 18, 1925. The plot numbers and treatments are given in table 1. Plot 3 received 800 pounds of acid phosphate for each 3-year rotation. Plot 5 received 1600 pounds of rock phosphate for each rotation. Plots 2, 3, and 5 receive the same nitrogen and potassium fertilizers. Displacement was made from the soil at a moisture content of 10 per cent. Three kilos of moist soil was packed in each of two displacement cylinders and successive 100-cc. portions of the displaced solu-

tion were obtained. The portions from the duplicate cylinders were combined for the determination of specific resistance, and of calcium and phosphorus. Displacement and all determinations were made in triplicate. The results given in table 1 are the average of the three series of determinations.

Lime applied to this slightly acid soil in 1915 at the rate of 2 tons to the acre

TABLE 1

Specific resistance, parts per million PO_4 and Ca in successive 100-cc. portions of the displaced solution from soil with the treatments indicated

Soil from Cullars rotation, Auburn, Alabama

PLOT NUMBER	FERTILIZER TREATMENT	PO_4 CONTENT		Ca CONTENT		SPECIFIC RESISTANCE	
		No lime	Lime	No lime	Lime	No lime	Lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*ohms*	*ohms*
	First portion of soil solution						
2	N, K	0.075	0.138	238	489	226	143
3	N, K, acid phosphate	0.260	0.420	492	753	113	89
4	None	0.206	0.267	228	468	312	206
5	N, K, rock phosphate	0.210	0.292	487	635	103	92
	Second 100-cc. portion of displaced solution						
2	N, K	0.079	0.134	220	360	267	178
3	N, K, acid phosphate	0.220	0.455	371	588	145	109
4	None	0.193	0.302	200	371	370	254
5	N, K, rock phosphate	0.226	0.288	384	510	124	110
	Third 100-cc. portion of displaced solution						
2	N, K	0.066	0.129	130	263	356	242
3	N, K, acid phosphate	0.197	0.374	261	430	198	145
4	None	0.188	0.306	144	290	471	292
5	N, K, rock phosphate	0.205	0.267	265	372	166	143
	Fourth 100-cc. portion of displaced solution						
2	N, K	0.060	0.129	111	195	498	327
3	N, K, acid phosphate	0.191	0.448	188	315	266	196
4	None	0.146	0.279	112	198	626	447
5	N, K, acid phosphate	0.183	0.301	197	227	230	217

had a marked influence on the solubility of the soil phosphorus. In plots 2 and 3, liming increased the phosphorus content of the soil solution 83 and 61 per cent respectively. The increase due to liming was not so great in the case of plots 4 and 5. The differences in the phosphorus concentration of the soil solution due to fertilizer treatment were greater on the limed than on the unlimed

soil. However, those differences were not as great as might be expected from a consideration of the history of the plots. As subsequent data will indicate, the phosphorus concentration of the soil extracts from these plots shows much greater differences due to phosphatic fertilization than are indicated in table 1.

A comparison of the successive portions of the displaced solution shows the relative solubility of phosphorus and other constituents of the soil solution. The data for calcium and for specific resistance indicate that the fourth 100-cc. portion is approximately 40 per cent as concentrated as the first 100-cc. portion or the soil solution. However, the phosphate concentration in the first and fourth portions is not very different. The fourth portion from the unlimed soil contains on the average approximately 80 per cent as much phosphorus as the soil solution. The fourth portion from the limed soil contains, with one exception, more phosphorus than the first portion. This increase in the phosphorus concentration of the successive portions is probably due to the high solubility of the phosphate and to the marked reduction in the calcium content

TABLE 2

Phosphate content of soil solution and 1:5 water extracts of soil with the treatments indicated

Soil from Cullar's Rotation, Auburn, Alabama

PLOT NUMBER	FERTILIZER TREATMENT	PO_4 CONTENT			
		Soil solution		1:5 extract	
		No lime	Lime	No lime	Lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
2	N, K	0.075	0.138	0.036	0.042
3	N, K, acid phosphate	0.260	0.420	0.336	0.490
4	None	0.206	0.267	0.012	0.020
5	N, K, rock phosphate	0.210	0.292	0.204	0.256

of the portions. As has been stated by Burd and Martin (5) a high calcium content of the soil solution may depress the solubility of phosphorus. This point will be considered in greater detail in connection with other data.

The PO_4 content of 1:5 soil extracts was determined in order to obtain further data on the solubility of soil phosphorus as influenced by liming and phosphatic fertilization. The extracts were prepared as previously described using collodion sacks. Table 2 gives the PO_4 content of the soil solution and of the 1:5 soil extract.

As has already been indicated, the differences due to phosphorus fertilization are more marked in the soil extracts than in the soil solution. The 1:5 extract of plots 2 and 4 which do not receive phosphate fertilization was much lower in phosphorus than the soil solution from these plots. The extract from plot 5, receiving rock phosphate, had a slightly higher concentration of phosphorus than the soil solution from the same soil. This difference was even greater in

the acid phosphate plot, the extract containing 0.490 p.p.m. PO_4 whereas the soil solution contained only 0.336 p.p.m.

The results obtained from the study of this soil indicate that liming materially increases the phosphate content of the soil solution or soil extract. The data in table 2 show that the effect of lime is greater when acid phosphate is used as a source of phosphorus than when rock phosphate is the source of phosphorus. Fertilization with acid phosphate produced a higher concentration of phosphate in the soil solution and in the soil extract than fertilization with rock phosphate.

Experimental fields at Albertville and Jackson, Alabama

Studies similar to the above were made on samples secured from rotation experiments on the experimental fields at Jackson and at Albertville, Alabama. The experiments afford a comparison of acid phosphate, rock phosphate, and basic slag on limed and unlimed soil. These plots were started in 1916. The phosphate fertilization with basic slag and acid phosphate is equivalent to 480 pounds of acid phosphate for each 3-year rotation. Twice this amount of rock phosphate is used. One series of plots was limed in 1916 at the rate of 2 tons to the acre. There has been no lime applied since that time. The Jackson soil is a Greenville sandy loam whereas the Albertville soil is Dekalb fine sandy loam. Both soils are medium acid according to the Truog test.

The water-soluble phosphorus in the soils from both fields was very low. The maximum concentration of phosphate in the soil solution from the Albertville field was 0.05 p.p.m. PO_4. The minimum concentration was 0.02 p.p.m. In the soil extract the concentration varied from a trace, probably 0.01 p.p.m. or less, to 0.069 p.p.m. The differences due to the form of phosphatic fertilization were small. Liming caused on average increase of 71 per cent in the phosphorus concentration of the soil solution and of 65 per cent in the soil extract. The detailed results are not given because no great dependence can be placed on the results from individual plots when the phosphate concentration is so low. The data are similar to those obtained with other soils, indicating the influence of liming on the solubility of the phosphorus.

The maximum concentration of phosphorus in the soil solution from the Jackson soil was 0.075 p.p.m. from the lime basic slag plot. The minimum concentration was 0.042 p.p.m. from the unfertilized unlimed plot. As with the Albertville soil, liming increased the concentration of phosphorus in the soil solution. The results obtained from the study of these two soils show the concentration of phosphorus in the soil solution may be very low and yet crop growth may be satisfactory. The fertilized plots in these experiments produce good crops of cotton, corn, and oats.

Phosphate experiments, Odin, Illinois

This experiment, started in 1904, affords a comparison of four forms of phosphatic fertilizer on an acid soil, some plots receiving 1 ton and others 8

tons of limestone to the acre. The soil is a gray silt loam on tight clay. The plots receiving 1 ton of lime are medium in acidity and have an average pH value of about 5.0. Those that have received 8 tons of lime are not acid according to the Truog test and average about pH 6.65. The different sources of phosphate were applied on the basis of equal money values instead of chemically equivalent amounts. The different sources, however, carry approximately the same amount of P_2O_5 except in the case of rock phosphate. The total amount of each phosphatic fertilizer applied to date is given in table 3. Hopkins et al. (9, p. 459) give the average crop yields and details of fertilization.

TABLE 3

Specific resistance, parts per million PO_4 and Ca in the first and second 200-cc. portions of the displaced solution from soil with the treatments indicated

Soil from Odin, Illinois

PLOT NUMBER	PHOSPHATE TREATMENT	PO_4 CONTENT		Ca CONTENT		SPECIFIC RESISTANCE	
		1 ton lime	8 tons lime	1 ton lime	8 tons lime	1 ton lime	8 tons lime
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*ohms*	*ohms*
	First portion of soil solution						
1	Steamed bone meal, 4200 pounds...	0.400	0.360	350	441	249	318
2	None.....	0.120	0.260	246	416	315	354
3	Acid phosphate, 7000 pounds.....	0.212	0.897	346	562	259	224
4	Rock phosphate, 14,000 pounds....	0.154	0 307	299	427	235	302
5	None.....	0.075	0.142	176	384	416	314
6	Basic slag, 5250 pounds.....	0.300	0.985	466	376	190	350
	Second portion of displaced solution						
1	Steamed bone meal, 4200 pounds...	0.446	0.265	236	308	378	485
2	None.....	0.080	0.236	178	237	470	560
3	Acid phosphate, 7000 pounds.....	0.107	0.772	231	375	395	354
4	Rock phosphate, 14,000 pounds....	0.100	0.273	214	257	347	358
5	None.....	0.049	0.152	124	260	610	445
6	Basic slag, 5250 pounds.....	0.245	1.045	265	244	296	550

Two experiments were carried out with this soil. The first consisted of a study of the displaced solution similar to that reported in table 1. The second was a study of the solubility of the soil phosphorus. The details of both experiments and the tabular results will be presented before discussing the results in detail.

For displacement, 2400 gm. of soil at a moisture content of 20 per cent were packed in the displacement cylinder. Two successive 200-cc. portions of the displaced solution were obtained from each cylinder. These were analyzed for phosphorus and calcium and the specific resistance was determined. Dis-

placement was in duplicate, the single determinations being made on different days. The results are given in table 3.

In the second experiment 40 gm. of soil was placed in a 150-cc. collodion sack, 100 cc. of water added and the sack placed in a 250-cc. beaker containing 100 cc. of distilled water. After 24 hours, the diffusate was removed and replaced with 100 cc. of distilled water; this process was repeated for 17 days. Each day the amount of phosphorus in the diffusate was determined. The soil was kept in suspension moderately well by hand shaking three times a day. The first day the solution removed was equivalent to a 1:5 extract; the second day it was theoretically equivalent to a 1:10 extract; the third day it was equivalent to a 1:20 extract. By removing one-half of the solution each day and replacing it with distilled water the proportion of water in the soil-water ratio would theoretically be doubled. Calculated on this basis the soil-water ratio on the seventeenth day would be 1:327,680; or if we assume that the initial extract contained 1.0 p.p.m. PO_4 and that no more phosphorus came into solution from the soil, then, according to the procedure followed, the diffusate on the seventeenth day would contain 0.000,015 p.p.m. PO_4. Such a calculation illustrates the degree to which the soil was washed by the dialyzing process. Considering the extent to which the soil was washed one would expect a considerable decrease in the phosphate concentration of the solution removed on successive days. The results of this experiment are given in table 4. The figures for the "no phosphate" plot are the average for the two unfertilized plots.

The results of these two experiments afford some interesting data relative to the influence of lime and of different phosphatic fertilizers on the phosphate content of the soil solution and of soil extracts. The data may be conveniently discussed by considering the influence of each form of phosphatic fertilizer on the behavior of phosphate in the soil. The several forms of phosphate will be considered in the order in which they appear in tables 3 and 4.

Steamed bone meal caused a higher concentration of phosphate in the soil solution and in the soil extracts from the light limed plots than any other form of phosphate. On the other hand the application of 8 tons of lime had a very marked depressing effect on the solubility of phosphate from steamed bone meal. This is most strikingly shown by a study of table 4. The phosphate content of the extract from the plot receiving 1 ton of limestone is consistently about 75 per cent higher than on the heavily limed plot. The reduced solubility of phosphorus in the bone meal plot due to heavy liming is also shown by comparing the phosphate content of the first and second portions of the displaced solutions. On the plot receiving 1 ton of lime the phosphorus content of the second portion was greater than that in the first portion or soil solution. This was the only plot in which that was true for the soil receiving the small amount of limestone. When the soil was heavily limed the phosphorus concentration of the solution from the bone meal plot decreased in the second

portion. The percentage decrease was greater than on any other plot receiving the same lime treatment.

It should be noted here that the phosphorus concentration of the extracts from all fertilized plots was considerably greater than the phosphorus concentration of the soil solution. Burd and Martin (5) have observed that in some instances the phosphorus concentration of the second, the third, or a later portion of the displaced solution is greater than of the first portion, the true soil solution. They attribute the increased solubility to a reduction of the salt content of the successive portions of the displaced solution. The salts, particularly those containing the calcium ion, would reduce the solubility of phosphates. That explanation is probably correct and serves to explain the differences in the phosphate concentration of the soil solution and soil extracts. To obtain a higher concentration of phosphorus in the extract than in the soil solution the presence in the soil of a considerable amount of readily soluble phosphate is essential. When the readily soluble phosphate is not present the phosphate content of the extract will generally be lower than that of the soil solution.

Apparently there are at least two factors determining the phosphorus concentration of the soil solution or extract. The first factor is the amount and nature of the phosphatic compounds in the soil. Readily soluble or readily hydrolyzed phosphorus compounds tend to produce a high concentration of phosphorus in the soil solution. Precipitated calcium phosphate is more soluble than iron and aluminum phosphates and consequently causes a higher phosphate content of the soil solution or extract. That is undoubtedly the reason liming increases the concentration of phosphorus in the soil solution from soils fertilized with acid phosphate. The second factor influencing the concentration of phosphorus is the amount and composition of salts in the soil solution or extract. A high concentration of calcium salts would depress the solubility of all forms of phosphorus in the soil. The first factor is doubtless the more important of the two. Thus liming the acid phosphate plot increased the concentration of phosphorus in the soil solution. At the same time the high calcium content of the soil solution of the limed plot had a depressing effect on the solubility of the phosphorus. This depression of the solubility is seen by comparing the phosphorus concentration of the soil solution given in table 3, and of the soil extract, table 4. However, the increased solubility resulting from the first factor was greater than the depression in solubility due to the second factor. The second factor, the calcium content of the soil solution, reduces phosphate solubility in both limed and unlimed soil.

A study of the data for calcium and for specific resistance, given in table 3, shows that there is no correlation between the calcium and the phosphorus content of the soil solution; neither is there a relation between the specific resistance and the calcium or phosphorus content. Plot 6, receiving basic slag is a striking illustration of this fact. The soil solution from the heavily

limed plot contains less calcium and has a greater resistance than the soil solution from the plot receiving the small application of lime. The phosphorus concentration of the solution, however, was increased 338 per cent by the heavy application of limestone.

The phosphorus concentration of the soil solution and of the extracts from the unfertilized plots was materially increased by heavy liming. This indicates that liming makes more available the native soil phosphorus as well as that added as acid phosphate or basic slag.

The beneficial influence of lime on phosphorus solubility was greater on the acid phosphate plot than on any other plot in the experiment. The heavy application of limestone increased the phosphorus concentration of the soil solution 420 per cent, and of the 1:5 extract, 750 per cent. As has been indicated this influence of lime can doubtless be attributed to the formation of calcium phosphates instead of iron and aluminum phosphates when the soluble phosphate reacts with the soil constituents.

Apparently, the availability of rock phosphate was not materially influenced by liming. The data in table 3 indicate an increased solubility due to the 8 tons of lime. The soil solution from the heavily limed plot contained 0.307 p.p.m. PO_4 compared with 0.154 p.p.m. from the plot receiving only 1 ton of lime. The data in table 4, on the other hand, indicate a depressed solubility due to liming. After the first day the phosphorus concentration of the extracts from the heavily limed plot was always less than that from the plot receiving 1 ton of lime. A large amount of evidence from field and greenhouse experiments indicates a depressed availability of the phosphorus of rock phosphate due to liming. The work on phosphorus solubility (table 4) indicates a considerably depressing effect but the work with the soil solution indicates an increased solubility due to lime.

The solubility of phosphorus in the basic slag plot is increased by liming to almost the same extent as that in the acid phosphate plot. Heavy liming increased the phosphorus content of the soil solution 338 per cent, and the phosphate concentration of the 1:5 extract, 1050 per cent. The maximum concentration of phosphorus in the extract was 2.24 p.p.m. PO_4 on the third day. On the same day the acid phosphate plot gave a maximum concentration of 3.0 p.p.m. PO_4 in the extract.

The results of these experiments are in accord with those of Prianishnikov (15), who found that lime depressed the assimilation of phosphorus from bone meal and from rock phosphate but either did not affect, or increased, the assimilation from acid phosphate. His experiments were in sand cultures with several crops as indicators of phosphorus assimilation.

The second experiment (table 4) shows the ability of the soil to renew the phosphorus content of the extract over a period of time. As has been indicated, the extract on the first day had a soil water ratio of 1:5. The proportion of water doubles on each succeeding day, giving a ratio of 1:20 on the third day, and 1:327,680 on the seventeenth day. A study of table 4 shows that the

maximum concentration of phosphorus was not found on the first day and in some instances not until the sixth day. Usually the maximum for the heavily limed plots was reached on the third day whereas the maximum for the lightly limed plots was reached on the sixth day. This increase in concentration after the first day may have been due to the reduction in the salt content of the extracts. Again, it may have been due to the fact that the soil remained in suspension somewhat better after the salt content was reduced. After reaching the maximum concentration the phosphorus concentration of the extracts gradually declined. The decrease in concentration was most rapid for the heavily limed acid phosphate and basic slag plots. In those plots the con-

TABLE 4

PO_4 content of the diffusate obtained on successive days from soil receiving the treatments indicated

Soil from Odin, Illinois.

PHOSPHATE AND LIME TREATMENT		PO_4 IN DIFFUSATE						
		First day*	Third day	Fifth day	Seventh day	Tenth day	Thirteenth day	Seventeenth day
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Bone meal	1 ton lime	1.200	1.480	1.520	1.280	1.160	0.960	0.720
	8 tons lime	0.700	0.840	0.760	0.700	0.680	0.560	.....
Acid phosphate	1 ton lime	0.370	0.600	0.700	0.080	0.700	0.620	0.500
	8 tons lime	2.800	3.000	2.400	2.000	1.920	1.600	1.160
Rock phosphate	1 ton lime	0.340	0.560	0.620	0.600	0.600	0.480	0.360
	8 tons lime	0.380	0.500	0.500	0.440	0.400	0.360	0.220
Basic slag	1 ton lime	0.200	0.340	0.340	0.480	0.420	0.400	0.280
	8 tons lime	2.100	2.240	2 240	1.720	1.520	1.240	0.820
No phosphate	1 ton lime	0.020	0.025	0.025	0.037	0.037	0.024	Trace
	8 tons lime	0.108	0.200	0.217	0.217	0.210	0.143	0.080

* The diffusate obtained the first day was equivalent to a 1:5 extract.

centration of the extract on the seventeenth day was less than one-half the concentration of the extract on the first day. When only 1 ton of lime was used with acid phosphate, rock phosphate, and basic slag, the phosphate concentration of the extract on the seventeenth day was greater than on the first day. It was, however, considerably lower than the maximum concentration of the sixth day. These three plots reached the maximum on the sixth day although that is not indicated in the table. Taken as a whole, the results indicate the remarkable ability of the soil to maintain a given concentration of phosphorus in the soil solution. The concentration maintained will vary a great deal from soil to soil but the phosphorus concentration in the soil solution

of one soil probably does not fluctuate a great deal. In this respect phosphorus differs from most of the other essential elements.

Fertility experiment, Toledo, Illinois

The plots, whose treatment is indicated in table 5, afford a comparison of the influence of liming on the native soil phosphorus and on phosphorus added in acid and rock phosphate. The soil is a gray silt loam on tight clay and is strongly acid by the Truog test. Hopkins et al. (9) give the detailed treatments and crop yields for these plots.

The soil was brought to a moisture content of 20 per cent for displacement. Displacement and the phosphorus determinations were made in duplicate. Table 5 gives the phosphate concentration of the soil solution and of the 1:5

TABLE 5

The phosphorus content of the soil solution and soil extracts from soil with the treatments indicated

Soil from Toledo, Illinois

PLOT NUMBER	TREATMENT	PO_4 CONTENT		
		Soil solution	1:5 extract	1:25 extract
		p.p.m.	*p.p.m.*	*p.p.m.*
301 N	L (2 tons)	0.142	Trace	Trace
301 S	None	0.050	Trace	Trace
306 S	R	0.039	Trace	Trace
307 S	R, L (8 tons)	0.433	Trace	Trace
305 N	R, AP (800 pounds)	0.050	0.120	0.120
306 N	R, RP (1 ton)	0.050	0.100	0.070
307 N	R, L (8 tons), AP (800 pounds)	0.445	0.400	0.200
308 N	R, L (8 tons), RP (4 tons)	0.373	0.090	0.045
309 S	R, L (8 tons), RP (tons), K	0.264	0.076	0.040

and 1:25 water extracts. The extracts were made in the usual manner, 21 hours being allowed for the system to come to equilibrium.

The results obtained with this soil confirm those already reported. In every instance liming materially increased the phosphorus content of the soil solution—in most cases, approximately 800 per cent. The results obtained with the extracts differ in several respects from those obtained with the soil solution. The extracts from all plots not receiving phosphatic fertilizers contained only a trace of phosphorus. Liming the unfertilized plot produced a large increase in the phosphorus content of the soil solution. However, the amount of readily soluble phosphorus must have been very low, for the extracts contained only a trace of phosphate. Liming materially increased the phosphate concentration of the extracts from the acid phosphate plots. The solubility of rock phosphate was apparently reduced by liming. The unlimed rock phosphate plot received only 1 ton of rock phosphate whereas the limed

plot received 4 tons. In spite of this higher rate of fertilization the extracts from the limed plots contained less phosphorus than the extracts from the unlimed plot. This is similar to the results obtained on the soil from the Odin field.

A study very similar to that made on the Toledo field was also made on soil from the Aledo, Illinois, field. The soil treatments were almost identical with those of the Toledo field. The soil is a strongly acid black clay loam. As considerable difficulty was experienced in displacing the soil solution, the results obtained for some plots are not very dependable. However, the results are similar to those obtained from the Toledo field except that the phosphorus concentration of the solution and of the extracts was lower and the influence of liming was not as great.

Wooster, Ohio and Berea, Kentucky soils

The soil solution from the limed and unlimed halves to plots 10 and 11 of the 5-year rotation at Wooster was obtained and the concentration of phosphorus determined. Considerable difficulty was experienced in obtaining the soil solution by displacement; consequently, the results are for single determinations and are therefore subject to error. Liming did not influence the concentration of phosphorus in the soil solution of the unfertilized plot, the concentration in both the limed and unlimed soil being 0.12 p.p.m. PO_4. The phosphate concentration of the solution from the fertilized plot was 0.13 p.p.m. in the unlimed soil and 0.18 p.p.m. in the limed soil. The extracts from these soils did not contain a determinable amount of phosphorus after the soil had been in the water 8 days.

Studies similar to the above were made on soil from seven plots from the Berea, Kentucky field (16). The water extracts of most of the plots did not contain a determinable amount of phosphorus. Liming increased the phosphate content of the solution from the acid phosphate plots from 0.094 p.p.m. to 0.280 p.p.m. Liming had no influence on the phosphate content of the plots receiving manure or rock phosphate. These results confirm those that have been presented in more detail.

THE CONCENTRATION OF PHOSPHORUS IN THE SOIL SOLUTION AND SOIL EXTRACTS AS RELATED TO PLANT GROWTH

Numerous attempts have been made to secure a laboratory method that will give an accurate measure of the availability to plants of phosphorus in the soil. Some of the methods that have been advanced for the purpose have been partially successful. None of the methods, however, can be considered wholly successful.

A study of the relation between the concentration of the phosphorus in the soil solution and its availability would seem desirable. The results reported in this paper make possible such a study on a limited number of soils whose fertilizer treatment and productive power are known.

The data secured do not indicate a close correlation between the phosphorus content of the soil solution and the availability of the phosphorus in different soils. In fact the data indicate that the phosphorus content of the water extract is in some instances a better criterion of phosphorus availability than the phosphate content of the soil solution. The results secured with the soil from the Toledo field (table 5) serve to illustrate this fact. The plot receiving residues and 8 tons of limestone had almost the same concentrations of phosphorus in the soil solution as the plot receiving acid phosphate in addition to residues and limestone. The plot receiving acid phosphate and residues but no lime had less than one-eighth as much phosphorus in the soil solution as the plot receiving residues and lime. The results are: 0.05 p.p.m. PO_4 for the "residue and acid phosphate" plot; 0.433 p.p.m. PO_4 for the "residue and lime" plot, and; 0.455 for the "residue, acid phosphate, and lime" plot. The results are not in accord with expectations regarding the availability of the phosphorus to crop plants. The corresponding figures for phosphorus in the 1:5 soil extracts are: trace, 0.12 p.p.m. and 0.4 p.p.m. These results are in the order we would expect from our knowledge of the plots. A study of the data from the Cullar's rotation plots, given in table 2, also shows that the water extracts give results that are in better agreement with the known availability of the soil phosphorus than the results obtained from a study of the soil solution. Apparently, under the conditions of this investigation, the phosphorus content of the soil solution indicates the maximum concentration of phosphorus that can be found in the soil under the particular conditions of salt content and reaction—an equilibrium has been established between the soil solution and the solid phase. On the other hand, the concentration of phosphorus in the soil extract seems to be a good index of the ability of a soil to maintain the phosphorus content of the soil solution.

The water extracts from several of the soils studied give results entirely different, however, from those to be expected from our knowledge of the plots. The soil from plot 11 of the 5-year rotation at Wooster, Ohio gave an extract that contained only a trace of phosphate and yet the average corn yield from this plot is 43 bushels. Likewise, the soil from the unfertilized plot of the Aledo, Illinois field gives an extract very low in phosphorus but the plot has an average corn yield of 56.1 bushels. Similar results were secured from the plots of the Berea, Kentucky field. It is evident, therefore, that the phosphorus content neither of the soil solution nor of the soil extracts is a good indicator of the relative availability of phosphorus in different soils. There is, apparently, another factor or group of factors, influencing phosphorus availability that as yet has not been thoroughly studied or measured. The amount and nature of the soil colloids is undoubtedly one important factor to be considered in some detail. Before definite conclusions can be drawn regarding the problem of phosphorus availability it will be necessary to make a more thorough study on a number of soils, including greenhouse studies on the

response of different crops to phosphatic fertilization when grown on different soils.

Another phase of the phosphorus problem of interest in connection with the results obtained is that of the absorption of phosphate by plants from solutions of different concentrations. The concentration of phosphorus in the soil solution is evidently very low, rarely 1.0 p.p.m. PO_4 and frequently as low as, or lower than, 0.1 p.p.m. The concentration of phosphorus in the fertilized plots of the Aledo, Illinois field was approximately 0.1 p.p.m. PO_4. Do plants secure their phosphorus from solutions of such low concentration? Most culture solutions contain over 100 p.p.m. PO_4. Hoagland and Martin (8) have shown that barley will make a good growth in culture solutions containing as low as 1.1 p.p.m. PO_4. When the concentration was reduced to 0.7 p.p.m. the yield of barley was considerably reduced. Their results indicate that growth would be poor in a solution containing only 0.1 p.p.m. PO_4. If this is the case how can one explain phosphate absorption by the plant? Does the plant secure its phosphorus from the same soil solution that is obtained by the displacement method? A study of the application of Donnan equilibria to soils has led the writers to believe that the plant does not necessarily obtain all of its phosphorus from this soil solution. It seems probable that the plant may obtain most of its phosphorus from a solution at the surface of the soil particle and that the phosphate concentration of this solution may be considerably greater than that of the remainder of the soil solution.

According to the Donnan theory of membrane equilibria non-diffusible ions on one side of a membrane cause an unequal distribution of the diffusible ions on the two sides of the semipermeable membrane. Donnan (7), discussing the application of the theory to soils, states that the presence of a membrane is not necessary to the establishment of a Donnan equilibria. Loeb (11, chapter 9) has shown that such an equilibrium is established when particles of gelatin are suspended in solutions. Wilson (4) gives an explanation of the Donnan theory as applied to colloidal particles. He also explains some of the properties of colloidal gold on the basis of the Donnan theory. The authors (17) have suggested the Donnan theory as an explanation of the fact that a soil suspension will invert more sugar than a soil extract of the same hydrogen-ion concentration. The soil particles of an acid soil contain alumino silicates that act as non-diffusible ions. They cause an unequal distribution of the hydrogen-ion at the surface of the particle and in the free soil solution, the H-ion concentration being greatest at the surface of the particle. In a similar manner the soil particles contain compounds of iron, of aluminum, and of calcium that behave as non-diffusible ions. These compounds would, therefore, cause a higher concentration of phosphorus at the surface of the particle than in the soil solution that is obtained by displacement. The plants may, therefore, obtain their phosphorus from this more concentrated solution at the surface of the particle. Using the above explanation as a working hypothesis

the writers are conducting some experiments to determine the validity of the explanation. The data secured will be presented in a subsequent paper.

There is some evidence in the literature indicating that plants obtain their phosphorus from a more concentrated solution at the surface of the soil or phosphate particle. The experiments cited do not offer positive proof of the suggested hypothesis but they are subject to that interpretation.

Kossovitch (10) has shown that plants grow much better in sand cultures in which rock phosphate is mixed with the sand than in similar cultures which derive all their phosphorus from the daily leaching of cultures containing rock phosphate. He attributes the increased growth of plants in the first series to the action of the roots on the particles of phosphate. However, it may be that the concentration of phosphorus at the surface of the phosphate particles was much greater than in the leachings from the culture. Marias (12) has shown that root development of plants in sand cultures containing plates of insoluble phosphate, is limited almost exclusively to the surface of the phosphate plates. Undoubtedly the plants secured practically all of their phosphate from the surface of these phosphate plates. The experiment indicates that the contact of the roots with the particles of insoluble phosphate is essential to growth. This may be due to the fact that the roots have a corrosive or solvent action on the phosphate or to the fact that the phosphate concentration at the surface of the particle is higher than in the remainder of the culture solution. Therefore, the plants would secure their phosphorus from the more concentrated solution. The concentration of phosphorus in the remainder of the solution was probably too low to permit absorption by the plant.

SUMMARY

The experiments reported were undertaken to determine the influence of lime and of different phosphatic fertilizers on the concentration of phosphorus in the soil solution and in soil extracts. The study was made on soils from field experiments in Alabama, Illinois, Ohio, and Kentucky. The phosphatic fertilizers used in the experiments included acid phosphate, rock phosphate, steamed bone meal, and basic slag.

The soil solution was obtained by the displacement method. Soil extracts were prepared by use of collodian sacks, the diffusate being used for the determination of phosphorus. The latter was determined by a rapid, sensitive colorimetric method.

Liming increased the phosphorus content of the soil solution and of the extracts from soils receiving acid phosphate or basic slag. The influence of lime on the solubility of rock phosphate was not great; in some cases it apparently increased, and in others reduced, the availability of rock phosphate. Liming had a very decided, depressing effect on the solubility of phosphorus in steamed bone meal.

The results of an experiment show that the soil has a remarkable capacity for maintaining a given concentration of phosphorus in the soil extract.

The relation of the results to the absorption of phosphorus by plants is discussed. It seems doubtful whether plants absorb all of their phosphorus from solutions of as low a concentration as the soil solution. In the soils studied, the soil solution rarely contained 1.0 p.p.m. PO_4; frequently it was less than 0.1 p.p.m. Reasoning from the basis of an application of the Donnan theory of membrane equilibria the authors advance the hypothesis that the concentration of phosphorus at the surface of the soil particle is greater than in the soil solution obtained by displacement. A plant probably absorbs some of its phosphorus from this more concentrated solution at the surface of the soil particle.

REFERENCES

(1) AMES, J. W., AND SCHOLLENBERGER, C. J. 1924 The availability of phosphorus in calcareous and non-calcareous soils. Ohio Agr. Exp. Sta. Bul. 380.

(2) ATKINS, W. F. G. 1924 The rapid determination of available phosphate in soil by the Coeruloe-molybdate method of Deniges. *Jour. Agr. Sci.* 14: 192–197.

(3) BRIGGS, A. P. 1922 A modification of the Bell-Doisy phosphate method. *Jour. Biol. Chem.* 53: 13–16.

(4) BOGUE, R. H. 1924 The Theory and Application of Colloidal Behavior, v. 1 (chap. 1). New York.

(5) BURD, J. S., AND MARTIN, J. C. 1923 Phosphate behavior in soils. *Science* 58: 227.

(6) BURD, J. S., AND MARTIN, J. C. 1923 Water displacement of soils and the soil solution. *Jour. Agr. Sci.* 13: 265–295.

(7) DONNAN, F. G. 1924 Discussion at the Farady Society symposium on base exchange in soils. *Trans. Faraday Soc.* 20: (3) 572.

(8) HOAGLAND, D. R., AND MARTIN, J. C. 1923 A comparison of sand and solution cultures with soil as a medium for plant growth. *Soil Sci.* 16: 367–388.

(9) HOPKINS, C. G., et al. 1919 Illinois crop yields from soil experiment fields. Ill. Agr. Exp. Sta. Bul. 219.

(10) KOSSOVITSCH, P. S. 1902 The rôle of the plant in dissolving the plant-food of the soil. *Zhur. Optn. Agron.* (Russ. Jour. Exp. Landw.) 3 (2): 145–180.

(11) LOEB, JACQUES 1922 Proteins and the Theory of Colloidal Behavior. New York.

(12) MARIAS, J. S. 1922 The comparative agricultural value of insoluble mineral phosphates of aluminum, iron, and calcium. *Soil Sci.* 13: 355–409.

(13) PARKER, F. W. 1921 Methods of studying the concentration and composition of the soil solution. *Soil Sci.* 12: 209–232.

(14) PARKER, F. W. 1925 Phosphate absorption by Pasteur-Chamberland filters. *Soil Sci.* 20: 149–159.

(15) PRIANISHNIKOV, D. N. 1911 The influence of calcium carbonate on the action of different phosphates. *Landw. Vers. Sta.* 75: 357–376. Abs. in *Exp. Sta. Rec.* 26: 527.

(16) ROBERTS, GEORGE, AND EWAN, A. E. 1920 I. Report on soil experiment fields. II. Maintenance of soil fertility. Ky. Agr. Exp. Sta. Bul. 228.

(17) TIDMORE, J. W., AND PARKER, F. W. 1924 Methods of studying the strength of soil acids. *Soil Sci.* 18: 331–338.

SYNTHETIC CALCIUM SILICATES AS A SOURCE OF AGRICULTURAL LIME: II. A COMPARISON OF THEIR INFLUENCE WITH THAT OF OTHER FORMS OF LIME UPON CERTAIN MICROBIOLOGICAL ACTIVITIES IN THE SOIL[1]

R. MARLIN BARNETTE[2]

New Jersey Agricultural Experiment Station[3]

Received for publication July 1, 1925

A comparative study of the influence of several different forms of lime on plant growth was reported elsewhere (1). Certain bacteriological studies were made parallel with those vegetation studies, with particular reference to the influence of synthetic calcium silicates as carriers of agricultural lime. The microbiological factors investigated in this connection were: (*a*) bacterial numbers, (*b*) nitrate formation and (*c*) sulfate formation. The numbers of microorganisms and the nitrate formation in the soil were selected because, as Waksman has shown elsewhere (25, 26), the results obtained from a study of these factors can serve as functions of the microbiological condition of the soil. The results are briefly reported here.

INFLUENCE OF VARIOUS FORMS OF LIME UPON BACTERIAL NUMBERS IN THE SOIL, AS DETERMINED BY THE PLATE METHOD

Déhérain (7) reported interesting data on the increase in numbers of bacteria with increased applications of calcium carbonate. Fischer (9) found that both calcium oxide and calcium carbonate produced an increase in the number of bacteria in the soil, especially where small amounts were used (e.g., 0.1 per cent CaO). With the addition of lime the bacteria increased in greater proportion than the molds. Engberding (8), Brown (3), and Bear (2), working usually with one form of lime, have observed an increase in bacterial numbers with applications of lime. Hutchinson (12) observed that whereas small amounts of CaO increased the bacterial numbers, large applications decreased the numbers. Connor and Noyes (6) observed that on some soils magnesite encouraged the multiplication of both aerobic and anaerobic bacteria more than did calcite, whereas on other soils the reverse was true. As shown elsewhere (25) the

[1] Part II of a dissertation presented to Rutgers University in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] The author takes this opportunity to express his appreciation of the sincere interest manifested by Dr. Selman A. Waksman in the direction of this problem.

[3] Now Assistant Chemist, Soils, University of Florida Agricultural Experiment Station, Gainesville.

continued application of lime to a Sassafras soil resulted in a decrease in the number of fungi and an increase in the number of bacteria and especially of actinomyces.

In these experiments, a study was made on the influence of ground limestone, of calcium hydrate, and of di-calcium silicate on the bacterial numbers of a Sassafras loam removed from experimental plots N and 11A of the station. The soil from plot N has received annual applications of muriate of potash and acid phosphate for over ten years. The soil from plot 11A has received annual applications of potash, acid phosphate, and nitrogen in the form of

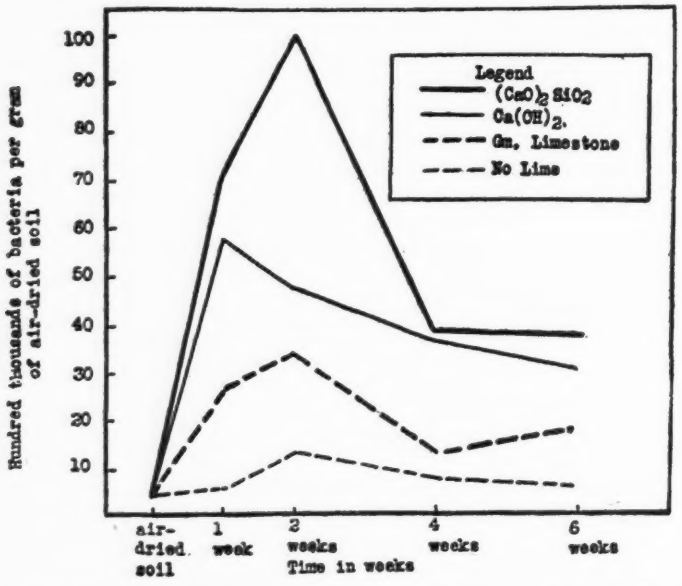


FIG. 1. SHOWING THE VARIATIONS IN THE NUMBERS OF BACTERIA IN SOIL FROM PLOT N TREATED WITH DI-CALCIUM SILICATE, CALCIUM HYDRATE, AND GROUND LIMESTONE ON AN EQUIVALENT LIME BASIS AT VARIOUS INTERVALS AFTER TREATMENT

ammonium sulfate for over ten years time, but no lime, and was therefore very acid (pH = 4.05).

Quantities of these two soils were weighed into pots and treated with calcium hydrate, ground limestone, and di-calcium silicate on an equivalent CaO basis. A constant moisture content was maintained and samples were taken at intervals for the determination of the bacterial numbers, sodium albuminate agar (10) being used. Two plates of two dilutions were made and incubated at 28°C. Counts were made after 24- and 48-hour incubations.

The treatments used and the numbers of bacteria expressed as hundred thousands per gram of air-dried soil are given in table 1. In both soils the

bacterial numbers increased to a maximum within one or two weeks and decreased to almost a constant number within the following few weeks. It is significant that the influence of air-drying followed by moistening should produce this result not only in all of the variously limed soils but also in the untreated soils, this effect corresponding to partial sterilization [Waksman and Starkey, (27)]. Similar results were obtained by Rahn (23) and Heinze (11).

The bacterial numbers of the soil from plot N were, on an average, influenced by the application of di-calcium silicate, of calcium hydrate, and of ground

TABLE 1

Bacterial numbers in soils from plot N and plot 11 A treated with various forms of lime on an equivalent lime (CaO) basis*

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	AIR-DRIED SOIL	AFTER 1 WEEK	AFTER 2 WEEKS	AFTER 4 WEEKS	AFTER 5 WEEKS	AVERAGE
	pounds						
Soil from plot N†							
No lime	2,000	4.50	5.87	13.90	8.70	5.95	8.61
16.30 gm. ground limestone	2,000		26.00	34.40	13.40	22.80	21.25
19.20 gm. di-calcium silicate	2,000		70.00	100.00	38.80	37.60	61.60
11.70 gm. calcium hydrate 4.27 gm. hydrated silica	2,000		57.00	46.60	36.20	30.00	42.70
Soil from plot 11 A‡							
No lime	2,000	3.60	15.94	10.50	8.60	4.94	7.49
9.06 gm. ground limestone	2,000		26.00	68.00	38.30	32.40	41.17
10.66 gm. di-calcium silicate	2,000		55.00	55.60	61.00	48.20	54.95
6.50 gm. calcium hydrate	2,000		32.00	28.00	30.00	32.80	30.70

* Expressed in hundred thousands per gram of air-dried soil.

† 18 pounds of soil per pot.

‡ 10 pounds of soil per pot.

limestone in order. (Fig. 1.) If the differences in the average relative crop yields as reported in a previous publication (1) are taken as significant, a very interesting correlation is found between crop yields and the stimulating effect of different forms of lime upon bacterial numbers. The same general trend is observed with the soil from plot 11A, though the correlation is not so perfect.

INFLUENCE OF VARIOUS FORMS OF LIME UPON NITRATE FORMATION IN SOIL

The favorable influence of lime generally observed, both in the field and in laboratory studies, upon nitrate formation in the soil has been found to be due

TABLE 2

Nitrification of ammonium sulfate in soil treated with increasing amounts of Limosil and with several forms of lime as an equivalent CaO basis

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	SOIL FROM 11A			SASSAFRAS LOAM			PENN LOAM		
		pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified	pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified	pH of soils at beginning of nitrification	Increase in N as NO_3 for each 100 gm. soil*	N added as $(NH_4)_2SO_4$ nitrified
	pounds		*mgm.*	*per cent*		*mgm.*	*per cent*		*mgm.*	*per cent*
Nothing	.....	4.05	−1.00		5.45	0.254	0.479	6.4	11.153	21.04
Limosil	500	5.30	0.149	0.281	5.50	0.578	1.090	6.7	14.430	27.22
Limosil	1,000	5.30	1.248	2.354	5.80	1.526	2.880	6.8	12.938	24.40
Limosil	2,000	5.85	3.899	7.356	6.05	5.928	11.190	6.9	21.117	39.80
Limosil	4,000	6.40	10.814	20.403	6.50	12.017	22.720	7.2	37.987	71.55
Limosil	2,000	5.85	3.899	7.356	6.05	5.928	11.190	6.9	21.117	39.80
Ground limestone	2,000	5.90	4.841	9.134	6.10	7.072	13.350	6.7	18.404	34.37
Calcium hydrate	2,000	5.90	3.451	6.511	5.90	5.239	9.880	6.8	21.390	40.30
Di-calcium silicate	2,000	5.90	2.640	4.981	5.90	9.315	17.580	6.9	15.634	29.52

* Air-dried basis.

largely to the neutralization of the acids formed in this process, thus creating a more favorable medium for the activities of the bacteria concerned. As a matter of fact, it has even been found (26) that in the case of an acid soil there is a direct relation between the amount of nitrate formed from ammonium salts and the buffering power (or presence of available base) of the soil. The erroneous idea of some early workers that nitrates are not formed in acid soils has been disproved by numerous investigators, however an adequate supply of basic materials was found to increase the speed of nitrate formation. In the numerous investigations reported, various forms of lime have been used with practically similar results: an increase in nitrification due to liming [Noyes and Connor (21) and Waksman 26)].

Soils previously treated with various liming materials and cropped several times (1),[4] were used in further experiments on the effect of increasing amounts of limosil on the nitrification of ammonium sulfate, and for a comparison of the effects of various liming materials furnishing the same amount of CaO. Soils

TABLE 3

Relation between increase in nitrate nitrogen (per 100 gm. of air-dried soil) and increased yield of crops on two soils treated with increasing amounts of limosil

LIMOSIL TREATMENT*	EQUIVALENT APPLICATION OF CaO PER ACRE	SOIL FROM PLOT 11A		SASSAFRAS LOAM	
		Increase in weight of crop over no lime pot	Increase in nitrate N over no lime†	Increase in weight of crop over no lime pot	Increase in nitrate N over no lime
gm.	*pounds*	*gm.*	*mgm.*	*gm.*	*mgm.*
2.769	500	12.6610	0.149	5.4599	0.324
5.538	1,000	14.8367	1.248	6.8327	1.272
11.076	2,000	20.8974	3.899	8.3571	5.674
22.152	4,000	24.9890	10.814	13.5445	11.763

* 10 pounds of soil per pot.

† Based on laboratory studies.

from the acid plot 11A of the New Jersey plots, from an old unlimed grass land (Sassafras loam), and from a well-limed alfalfa field (Penn loam) were used in these experiments. Short descriptions of these soils were given elsewhere (1). After the removal of the last crop, the three soils used under various lime treatments in pot culture work were thoroughly air-dried and used for the study of nitrate formation. Fifty-three milligrams of nitrogen in the form of ammonium sulfate was added to 100 gm. of soil placed in tumblers, and each soil was brought to its optimum moisture content.

At the end of an incubation period of 28 days a 1 to 5 water extract of the soil was made and the nitrates were determined by the phenoldisulfonic acid method. Alum was used as a clarifier when necessary. Excellent agreement was obtained in the tumblers of like treatment. Table 2 gives the treat-

[4] Limosil is an impure product—possibly a mono-calcium silicate is present as well as about 13 per cent free lime. The product contains about 41 per cent total CaO.

ments, the increase in nitrate nitrogen content, and the percentage nitrification of the nitrogen added as ammonium sulfate.

Increased nitrification of ammonium sulfate followed with the increased application of limosil, the single exception being the 1000-pound application on the Penn loam. As would be expected, the several forms of lime were individual in their effects on nitrification in the various soils. For this reason there can be no correlation between nitrification as studied under laboratory conditions and the several crop yields. However, as shown in table 3, there is a correlation between the gain in nitrates produced by a given material (i.e. limosil) and the increase in crop production. Figure 2 shows the correlation between increase in nitrate production and increase in crop yield as obtained with the soil from plot 11A.

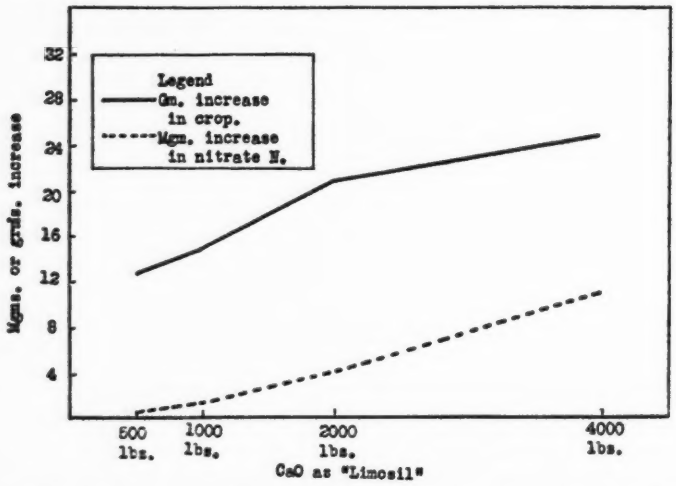


FIG. 2. SHOWING CORRELATION BETWEEN INCREASE IN CROP PRODUCTION AND INCREASE IN NITRATE NITROGEN (PER 100 GM. OF AIR-DRIED SOIL) IN SOIL FROM PLOT IIA TREATED WITH INCREASING APPLICATIONS OF LIME AS LIMOSIL

Though the rate of nitrification may vary with the form of lime used, yet a final and maximum production of nitrates (for a given set of conditions) in soils treated with the different forms of lime on an equivalent lime basis must be the same, at least under conditions precluding leaching of the soil. Thus when two soils were treated with various forms of lime and left standing under favorable conditions of temperature and moisture for a period of 30 weeks, the results as indicated in table 4 were obtained. No nitrogen-carrying compounds were added.

In the Elkton silt loam and in the Sassafras loam, the final accumulation of nitrates was the same, regardless of the form of lime applied, where the same

amount of lime (CaO) was furnished in the various forms. From the meager data at hand it is impossible to say which form of lime causes nitrification to proceed at the greatest rate. It seems plausible, however, that those forms which are the more soluble and hence more active chemically, e.g., the oxide and hydrate, would bring about a very favorable condition for nitrification immediately after application, if not applied in amounts which inhibit bacteriological processes, as shown by Fischer (9) Hutchinson (12), Hutchinson and MacLennan (13), Miller (20), Waksman and Starkey (27) and others.

THE INFLUENCE OF VARIOUS FORMS OF LIME UPON SULFATE FORMATION IN THE SOIL

The most extensive works on the effect of lime on the removal of sulfur from the soil are the lysimeter experiments of Lyon and Bizzell (16, 17) and MacIntire and associates (18). The study of the leachings from limed and unlimed soil indicates that applications of lime tend to increase the removal of sulfates from the soil. Lyon (15) in a review of many experiments makes the statement:

TABLE 4

Influence of several forms of lime applied on an equivalent lime basis on the nitrification of soil nitrogen

TREATMENT	ELKTON SILT LOAM*		SASSAFRAS LOAM†	
	N as NO_3 per 100 gm. soil	Relative nitrate content	N as NO_3 per 100 gm. soil	Relative nitrate content
	mgm.		*mgm.*	
No lime	3.09	100	3.94	100
Calcium oxide	7.69	249	5.88	149
Calcium hydrate	7.70	249	6.63	168
Ground limestone	7.69	249	7.00	177
Di-calcium silicate	7.70	249	6.25	158
Limosil	7.33	237	5.75	145
Calcium oxide equivalent to free CaO in limosil	4.35	141	3.50	89

* Liming materials added to furnish 3200 pounds CaO per acre.

† Liming materials added to furnish 2000 pounds CaO per acre.

> The effect of liming on the removal of sulfur in the drainage water is difficult to understand. Apparently when conditions are made more favorable for nitrification they are not always more favorable for sulfofication. In other words, when liming increases nitrification it may or may not promote sulfofication. The data do not permit any further generalization. There is some indication, however, that a subsoil may absorb much of the sulfate formed in the upper soil.

The results obtained by other investigators, such as Plummer (22), Christie and Martin (5), Lipman and Gericke (14), Robinson and Bullis (24), and others, do not improve upon the generalizations of Lyon. Brown and Kellogg's

(4) investigations on the best method for the determination of sulfates in soils revealed some very interesting information relative to the solubility of soil sulfates in distilled water and in HCl. Their results indicate that extraction with distilled water is to be preferred to extraction with dilute HCl. More recently MacIntire and Shaw (19) have added further information to the subject by their excellent studies relative to the formation of double sulfates of calcium and aluminium or iron in the presence of an excess of calcium hydroxide.

In general it may be expected that the application of lime in the several forms to acid soils will increase sulfate and nitrate formation in the same manner. But definite prediction of the effect of lime on a given soil may not be made without knowledge relative to the forms of sulfur in the soil and to the microbiological processes. The present work gives the results of a study of

TABLE 5

The influence of increasing amounts of lime as limosil and equivalent applications in the several other forms on the readily soluble sulfates of two so-called acid soils and on a limed Penn loam

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	SO_4 PER 100 GM. SOILS		
		Soil from plot 11A	Sassafras loam	Penn loam
	pounds	*mgm.*	*mgm.*	*mgm.*
No lime		19.89	11.75	22.53
Limosil	500	26.07	12.75	23.14
Limosil	1,000	29.15	13.99	24.57
Limosil	2,000	34.29	18.01	24.57
Limosil	4,000	38.49	24.99	24.78
Limosil	2,000	34.29	18.01	24.57
Ground limestone	2,000	29.34	19.99	22.16
Calcium hydrate	2,000	30.39	17.83	26.86
Dicalcium silicate	2,000	34.18	20.16	22.53

the influence of several forms of lime on the accumulation of water-soluble sulfates in the soil under conditions precluding leaching.

The water-soluble sulfates of the soil from plot 11A, from the Sassafras loam, and from the limed Penn loam used in the other bacteriological studies were determined after the soil was cropped three times and thoroughly screened on removal from the pots. This was accomplished by shaking 200 gm. of soil with 500 cc. of distilled water for 4 hours, filtering the suspension first through a good quantitative filter and then through a Berkefeld filter. The sulfates were determined in the clear filtrate by precipitation with barium chloride. The results, expressed as milligrams of sulfate for 100 gm. of soil, are given in table 5. The amounts of sulfates adsorbed by the plants are not taken into consideration, but they cannot have been very great for the three crops removed. With increasing applications of limosil there is an increase in the sulfates of the soil from 11A and of the Sassafras loam. This increase is not ob-

served with the limed Penn loam. Thus the sulfate formation evidently may be correlated with increased nitrate formation in the former soils, but not in the latter. However, in this connection, it must not be forgotten that the nitrification studies were made in the laboratory and with the addition of nitrogenous materials, whereas the sulfates were formed from the native soil materials. The comparatively low yields of crops obtained on the Penn loam soil probably justify the assumption that both the nitrogen- and sulfur-bearing materials had been more completely decomposed in this well-limed soil, and that hence with further additions of lime there was little or no further decomposition.

A comparison of the results obtained with equivalent applications of limosil, of ground limestone, of calcium hydrate, and of di-calcium silicate, shows that these materials are similar in their influence on sulfate formation, and that equivalent applications give for all purposes the same amount of sulfate. Naturally, the rate of sulfate formation may vary for the several materials.

SUMMARY

A study of the influence of several forms of lime, particularly calcium silicates, on the bacterial numbers, on nitrate formation, and on sulfate accumulation in several soils gave rise to the following generalizations:

1. Chemically equivalent additions of ground limestone, of di-calcium silicate, and of calcium hydrate to soils deficient in basic materials increased the bacterial numbers in these soils in amounts varying with the form and the soil.

2. Following the addition of ground limestone, of di-calcium silicate, and of calcium hydrate a rapid increase in the number of bacteria, followed by a decrease to almost a constant number was observed. This is no doubt due to the increase in available energy as a result of neutralizing the acid reacting organic soil substances; after the energy made more readily available is used, the numbers of bacteria drop.

3. Some correlation was obtained between the fertility of the soils under the various lime treatments and the number of bacteria, as estimated by plating on sodium-albuminate agar.

4. With increasing applications of lime as limosil there is a corresponding increase in the formation of nitrates from ammonium sulfate. This increase can be correlated with increased yield of crop.

5. Though chemically equivalent amounts of ground limestone, calcium hydrate, di-calcium silicate, and limosil influenced differently the rate of nitrate formation, the final accumulations of unleached nitrate were the same, regardless of the form of lime.

6. Extracts of two acid soils and of one well-limed soil were made and analyzed for sulfates. The soils had been treated with increasing applications of limosil and with chemically equivalent applications of calcium carbonate, calcium hydrate, limosil and di-calcium silicate, held under conditions precluding leaching, and had been cropped three times. The two acid soils showed an increased sulfate formation with an increased application of limosil, but the well-limed soil showed very small increases of sulfate with an increased limosil application. Chemically equivalent applications of the four substances affected the sulfate formation in the same manner in the three soils, producing substantially the same amount of sulfates. This is no doubt due to the increased microbiological activities, which resulted in a greater decomposition of organic matter and, therefore, in a greater liberation of sulfur in the form of soluble sulfates.

7. The rapidity of the changes in the microbiological processes of the soil differed with

the nature of the material, though the final effects of chemically equivalent quantities of the several liming materials were the same. This may serve to explain the difference in the yields of the individual crops as a result of the different liming materials, although the averages of the results give practically no differences.

REFERENCES

(1) BARNETTE, R. M. 1924 Synthetic calcium silicates as a source of agricultural lime: I. A comparison of the influence of synthetic calcium silicates with other forms of lime as affecting plant growth. *Soil Sci.* 18: 479–492.

(2) BEAR, F. E. 1917 A correlation between bacterial activity and lime requirements of soils. *Soil Sci.* 4: 433–462.

(3) BROWN, P. E. 1911 Some bacteriological effects of liming. Iowa Agr. Exp. Sta. Research Bul. 2.

(4) BROWN, P. E., AND KELLOGG, E. H. 1914 Sulfofication in soils. Iowa Agr. Exp. Sta. Research Bul. 18.

(5) CHRISTIE, A. W., AND MARTIN, J. C. 1918 The chemical effects of CaO and $CaCO_3$ on the soil. Part II. The effect on water-soluble nutrients in soils. *Soil Sci.* 5: 383–392.

(6) CONNOR, S. D., AND NOYES, H. H. 1919 Natural carbonates of calcium and magnesium in relation to the chemical composition, bacterial contents, and crop-producing power of two very acid soils. *Jour. Agr. Res.* 18: 119–125.

(7) DÉHÉRAIN, P. P. 1893 Le travail de la terre et la nitrification. *Compt. Rend. Acad. Sci.* [Paris] 16: 1091–97.

(8) ENGBERDING, D. 1909 Vergleichende Untersuchungen über die Bakterienzahl im Ackerboden in ihrer Abhängigkeit von äussern Einflüssen. *Centbl. Bakt.* (II) 23: 569–642.

(9) FISCHER, H. 1909 Über den Einfluss des Kalkes auf die Bakterien eines Bodens. *Landw. Vers. Sta.* 70: 335–342.

(10) FRED, E. B., AND WAKSMAN, S. A. 1922 A tentative outline of the plate method for determining the number of micro-organisms in the soil. *Soil Sci.* 14: 27–28.

(11) HEINZE, B. 1920 Bakteriologische Versuche. *Landw. Jahrb.* 55: 139–184.

(12) HUTCHINSON, H. B. 1913 The partial sterilization of the soil by means of caustic lime. *Jour. Agr. Sci.* 5: 320–330.

(13) HUTCHINSON H. B., AND MCLENNAN, K. 1914 The relative effect of lime as oxide and carbonate on certain soils. *Jour. Agr. Sci.* 6: 302–322.

(14) LIPMAN, C. B., AND GERICKE, W. F. 1918 Does $CaCO_3$ or $CaSO_4$ treatment affect the solubility of the soil's constituents. *Calif. Univ. Pubs., Agr. Sci.* 3: 271–282.

(15) LYON, T. L. 1921 The effect of liming on the composition of the drainage water of soils. *Jour. Amer. Soc. Agron.* 13: 124–130.

(16) LYON, T. L., AND BIZZELL, J. A. 1916 The loss of sulphur in drainage water. *Jour. Amer. Soc. Agron.* 8: 88.

(17) LYON, T. L., AND BIZZELL, J. A. 1918 Lysimeter experiments. *N. Y. (Cornell) Agr. Exp. Sta. Memoir* 12: 72–78.

(18) MACINTIRE, W. H., WILLIS, L. G., AND HOLDING, W. A. 1917 The divergent effects of lime and magnesia upon the conservation of soil sulfur. *Soil Sci.* 4: 231–237.

(19) MACINTIRE, W. H., AND SHAW, W. M. 1925 The ternary systems $CaO–Fe_2O_3–CaSO_4$ and $CaO–Al_2O_3–CaSO_4$ as explaining the retention of sulfates by heavily limed soil. *Soil Sci.* 19: 125–151.

(20) MILLER, F. 1914 Über den Einfluss des Kalkes auf die Bodenbakterien. *Ztschr Gärungsphysiol.* 4: 194–206.

(21) NOYES, H. H., AND CONNER, S. D. 1919 Nitrates, nitrification and bacterial contents of five typical acid soils as affected by lime, fertilizer, crops and moisture. *Jour. Agr. Res.* 16: 27–42.

(22) PLUMMER, J. K. 1921 The effects of liming on the availability of soil potassium, phosphorus and sulphur. *Jour. Amer. Soc. Agron.* 13: 162–171.

(23) RAHN, B. 1908 Bakteriologische Untersuchengen über das Trocken des Bodens. *Centbl. Bakt.* (II) 20: 38–61.

(24) ROBINSON, R. H., AND BULLIS, D. E. 1922 Acid soil studies: III. The influence of calcium carbonate, calcium oxide and calcium sulphate on the soluble soil nutrients of acid soils. *Soil Sci.* 13: 449–459.

(25) WAKSMAN, S. A. 1922 Microbiological analysis of soil as an index of soil fertility: III. Influence of fertilization upon numbers of microörganisms in the soil. *Soil Sci.* 14: 321–346.

(26) WAKSMAN, S. A. 1923 Microbiological analysis of soil as an index of soil fertility VI. Nitrification. *Soil Sci.* 16: 55–67.

(27) WAKSMAN, S. A., AND STARKEY, R. L. 1923 Partial sterilization of soil, microbiological activities and soil fertility. *Soil Sci.* 16: 137–156, 247–268, 343–357.

CONTRIBUTION TO THE THEORY OF THE ORIGIN OF ALKALI SOILS

ALEXIUS A. J. DE'SIGMOND

Budapest, Hungary

Received for publication July 23, 1925

An understanding of the characteristic properties of a soil, necessitates a study of its origin. Since the publication of the author's monograph on the alkali soils in Hungary, some of the publications of W. P. Kelley, C. S. Scofield, J. S. Joffe and H. C. McLean, and especially the English translation of the papers of the Russian investigator, K. K. Gedroiz,[1] have appeared. These confirm the author's experiences, some of which might supplement the results of the others. Most of the author's investigations were published in Hungarian, during and after the war, and no opportunity presented itself to translate them into English or other international language. As the author has now been charged by C. F. Marbut, chairman of the Fifth International Soil Commission, to organize an international subcommittee for the study of alkali soils, he feels it necessary to make available for further discussion his own experiences. The author does not intend to discuss in this paper the whole material treated by the above quoted investigators and by himself, but to recapitulate the different theories on the origin of alkali soils.

The first scientifically supported theory on the origin of alkali soils was presented by E. W. Hilgard, who pointed out the difference between the littoral and the terrestrial salty soils. The latter were called alkali soils and were designated as a product of climate. According to this theory, they are the result of rainfall insufficient to leach out the salts that are formed progressively by the weathering of soils minerals; therefore, the more arid the climate, the more chance there is for the accumulation of alkali in the soil. Hilgard treated the alkali soils as more or less impregnated with different sodium salts and emphasized largely the obnoxious effects of the latter on crops and fruit trees. In all his publications on this subject, he stressed the fact that if the obnoxious salts are leached out, a soil of good fertility and of normal physical properties is formed. According to this theory, the problem of alkali-reclamation consisted chiefly in washing out these harmful soil constituents by irrigation and drainage.

The author is far from minimizing the high merits of the old master on alkali

[1] Translated by S. A. Waksman of the New Jersey Experiment Station, New Brunswick, N. J., and mimeographed under the supervision of C. S. Scofield, U. S. Department of Agriculture, Washington, D. C.

reclamation. His pioneer work represents fundamental experiences in the utilization of alkali lands, and was the real starting point in the systematic reclamation all over the world. When, however, the author began in 1900 to study the Hungarian alkali soils, called "Szik"- or "Szék"-lands, he was immediately struck by two difficulties that could not be explained by the above-mentioned alkali theory. In the first place: Why are alkali soils scattered right amidst the best wheat soils? There is no appreciable difference in the climatic conditions and very often none in the topographic conditions which could throw light on the origin of alkali accumulation; for example, very frequently the worst alkali spots are found on the more level parts of the land. The second evidence against the alkali theory of Hilgard consisted in the fact that a considerable part of the alkali soils in Hungary, though practically deficient in sodium carbonate, and very poor indeed in water-soluble salts—ranging no higher than 0.15 to 0.20 per cent in the soil—proved *practically impermeable* to water and air, and showed the same physical properties as the real black alkali soils described by Hilgard. When moistened, the soil becomes fluid and fills up the cracks and fissures of the underlying soil layers, which were previously dry; hence, the checkered appearance of the upper horizons, frequently observed in this class of alkali soils. This liquefying property of the surface horizon is very characteristic of this type of alkali soil and, as will be seen later, bears the proper relation to the composition of the so-called zeolite-humus-complex of the soil, regardless of the temporary salt content or occurrence of black alkali in the soil. It sounds paradoxical that the wetting or the penetration of the water in this liquescent matter is extremely slow and does not reach any considerable depth. Hilgard ascribes the impermeability and puddling of the alkali soil to the carbonate of soda. In this case no carbonates whatever are found in the soil, but we have to do here with a zeolite-humus-complex saturated more or less with sodium ions, or with amorphous sodium zeolites and humates in a colloidal dispersion. When dry, the soil becomes hard like stone and quite untillable. In the second soil horizon, nearer to the surface, is found the impervious hardpan, called "Szikfok," impregnated with dark colored humus and colloidal zeolites. This horizon has a more or less developed structure, resembling the profile of the Russian "Solonetz." Here again very often the salt content is quite inconsiderable and the carbonate of soda quite absent, showing that contrary to Hilgard's belief, *the occurrence of this type of hardpan is independent of the presence of sodium carbonate.*

The first adverse criticism of Hilgard's theory was soon eliminated by the study of the mechanical and physical condition of the alkali soil profiles, showing that *in every case of alkali accumulation*, even in the sandy alkali soils, *an impervious subsoil* is found. Moreover, at certain times a close relation is found between the depth of the impervious soil-layer and the accumulation of the salts, the latter being the more accentuated, the nearer it is to the impervious subsoil. This might be illustrated by the profile of the soil-section of an

irrigated alkali land at Békéscsaba surveyed by the author as far back as 1903 (12, 14). It may be of some interest to see how the fluctuation of the salt content and the depth of the impervious subsoil interfere; therefore since the authors original publications in Hungarian would hardly be available to American investigators and since the Proceedings of the First Agrogeological Conference, in which the author's results have been briefly reported in German, are already unavailable they are briefly summarized here. The distribution of the total salts to an average depth of 120 cm. is reproduced on the soil map

TABLE 1

Mechanical analysis of Békéscsaba and Cservenák soils

DIAMETER OF SOIL FRACTIONS	ALKALI SOIL AT BÉKÉSCSABA PLOT 38			WHEAT SOIL OF CSERVENÁK	
	Depth of the soil layer				
	0 to 30 cm.	60 to 90 cm.	190 to 220 cm.	0 to 30 cm.	230 to 270 cm.
mm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1–0.5	.....	.....	.....	1.86	21.41
0.5 –0.2	0.44	.....	0.42	23.32	11.99
0.2 –0.1	7.37	6.99	2.11	25.10	26.55
0.1 –0.05	22.56	16.85	5.46	17.10	10.49
0.05–0.02	10.63	16.45	13.02	5.88	8.14
0.02–0.01	6.07	2.68	4.62	2.41	4.71
0.01–0.0025	26.03	31.25	34.88	19.31	10.71
0.0025	26.90	25.78	39.49	5.02	6.00
Total.....	100.00	100.00	100.00	100.00	100.00

TABLE 2

Permeability of water in Békéscsaba and Cservenák soil-profits

Time when water disappeared.....	Not reached	Not reached	Not reached	5 hr. 20 min.
Depth to which the soil column became moist when water disappeared.....*mm.*	0	0	0	320
Final depth of the moistened soil column.....*mm.*	55	48	22	565
Water column above the soil, at the end of the experiment.....*mm.*	89	80	85	Nothing
Experimental period.....*days*	16	6	6	16

(plate 1), covering an alkali land of about 102 hectares. Samples were taken from two or more depths in about fifty different places, and the average salt content was used for the classification. The limits of the salt classes were mapped according to the natural or planted vegetation, because a close connection has been found to exist between the salt content of the soil and the vegetation supported by it. Consequently the salt classification is in full harmony with the cultural classification. The author does not intend to treat here in greater detail the methods of surveying, though they are in some

respects different from those used in America. He intends to show only how the vertical distribution of the four typical soil-horizons fluctuates in a cross-section through the different salt classes, along the ABCEDFGH-line on plate 1. This and the corresponding average salt-content are reproduced on plate 2. The uppermost horizon represents the limit of the more or less dark-colored humus-horizon, which is itself divided into at least two different horizons, i.e., the surface eluvial, and the subsurface accumulation horizon. The second horizon (plate 2) consists of a yellow marl with numerous concretions of calcium carbonate. Then follows, in different thicknesses, a sandy loam, rich in micas, and under this the impervious bluish clay, recovered in every alkali formation of similar type. If the corresponding salt-content in plate 2, figure 2 is now compared with the fluctuation of this impervious clay-horizon, it becomes evident that the nearer the latter approaches the surface, the more the salts accumulate.

Close to this alkali land, the best wheat-soils, with no trace of alkali, are found. It was interesting to investigate whether this impervious clay can be recovered here and to what depth. The soil examined was on the Cservenák farm, where, although the climatic conditions hardly differed from those of Békéscsaba, there was no trace of alkali in the soil. But, on the other hand, there was a striking difference in the mechanical composition, as well as in the physical properties of both soils. In table 1, the respective analyses of a heavy alkali soil-profile at Békéscsaba and on the farm of Cservenák are given.

The results of some experiments on the permeability of both soil-types are reported in table 2.

The data in both tables prove definitely that here we have to do with two soils of quite different physical properties, and especially that, in the case of the wheat soil of Cservenák, the drainage of the whole soil-profile is a good one whereas that of Békéscsaba is quite deficient. It seems very likely that the alkali salts in the case of the good soil were drained to the deeper soil-layers, and in fact, if a bore is made to a depth of 10 to 15 m., saline water is found similar in composition to the subsoil water of the alkali soil at Békéscsaba at a depth of about 2 or 3 m. Tables 3 gives the chemical composition of both waters.

It follows then that, under the climatic conditions prevailing in Hungary, the natural leaching of the alkali salts is possible when there is not an impervious subsoil, which prevents the natural drainage and causes the accumulation of the water-soluble salts in the upper layer.

The same was found in the sandy alkali soils. In this case a calcareous hardpan is found at a depth of about 1 to 3 m. under the sandy layer, again preventing any drainage. This hardpan is made up of the same sand with calcium carbonate. For the formation of this hardpan the black alkali present in these soils again might not be responsible, but there is every evidence of former swampy formations. On the other hand, the same calcareous hardpan is found in the more level parts of the adjoining soils where alkali does not

occur, showing that, in early times, when the stagnant water-level was higher than now, the swamp formation of this area was considerably greater. This is in full harmony with the historical fact, that, before the regulation of the streams, and the protecting of the lowland against the yearly inundations, the swampy and peaty areas were very considerable. Now in the lowest basins of this territory the typical black alkali soils are found.

Here the *third factor in the genesis* of the alkali soils is found; namely, under the semiarid climatic conditions found in Hungary the alkali occurrence coin-

TABLE 3

Chemical composition of subsoil water of Békéscsaba and Cservenák soils

	WATER, 210–240 CM. DEEP AT THE ALKALI FIELD NO. 12 AT BÉKÉSCSABA	DEEP-WELL-WATER IN THE CSERVENÁK FARM. DEPTH OF THE SPRING ABOUT 10–15 M.
	p.p.m.	*p.p.m.*
Na	2048.32	528.90
K	44.00	70.32
Ca	76.76	92.54
Mg	295.99	119.75
Cl	2214.00	105.10
SO_4	2474.82	908.29
NO_3	.....	45.52
$\frac{1}{2}CO_3$	.....	63.78
HCO_3	252.16	881.70
CO_2 (free)	547.30	Not determined
Total	7953.35	2815.93

Percentage composition of positive and negative ions in gram equivalents

		per cent	*per cent*	
Positive ions	Na	75.3	58.5	100
	K	0.9	4.6	
	$\frac{1}{2}$Ca	3.2	11.8	
	$\frac{1}{2}$Mg	20.6	25.1	
Negative ions	Cl	52.9	7.6	100
	$\frac{1}{2}SO_4$	43.6	48.2	
	NO_3	.....	1.9	
	$\frac{1}{2}CO_3$	3.5	5.4	
	HCO_3	.....	36.9	
Free CO_2		9.9	Not determined	

cides with that territory which was *temporarily overflowed with shallow water.* The intensive evaporation of water in the dry summer and the imperviousness of the subsoil which prevented any drainage, caused the water-soluble salts to accumulate more or less according to the local soil and hydrological conditions. The author does not assume that in the drier countries, like the deserts of Africa, of Asia and of America, where the evaporation factor may be more

effective, the accumulation of alkali may be a purely climatic effect, though even in that case the temporary abundance of soil-humidity seems to be necessary to dissolve the salts and to bring them by capillarity or seepage to the surface soil. The writer does not feel authorized to decide this question, but the occurrence of the alkali soils which were visited in the United States and in Egypt, as well as the publications of the respective countries affirm this supposition and agree with the theory of the Russian agrogeologist K. Glinka (4). In his book on the different types of soil-formation, Glinka treats the continental salty soils in a separate chapter, characterizing them as *products of temporary over-abundance of humidity*, pointing out that, under similar conditions in the humid climate, there would result real peats and swamps. But there is a striking difference in the soil-forming factors of the two related types. In the case of swamps, the soil is formed in a somewhat acid medium, in contrast to the reaction of alkali soils. By this he does not mean the true alkaline reaction of normal sodium carbonate, but includes all carbonates soluble in the soil moisture.

The author does not intend to treat in detail Glinka's classification of the different salines, which harmonizes in many respects with his own published in German some years before (16), but the discussion will be confined to the theory of soil-formation in alkaline medium suggested first by Glinka. He shows by different water extracts, that the soil solution of the solonetz type of soil is always alkaline, as the water extracts contain not only bicarbonates, but also normal carbonates which can be titrated with phenolphthalein. He further states, that the quantity of humus increases with the alkalinity of the soil-horizon. He suggests also that to dissolve humin substances the presence of normal carbonate of soda is required. An experiment is described which consists of treating a salt-free tschernozem with a solution of bicarbonate of soda or with the normal sodium carbonate, with the result that, in the first case, the percolation of the solution was very quick, and the percolate was faintly colored; in the case of the normal carbonate, the humus of the soil gave a dark solution, forming at a certain depth a dark-colored ring and preventing any further water movement. Similar phenomena have been observed repeatedly in the author's earlier experiments (12, 14). Nevertheless, to see how these phenomena change with the concentration and the mixing-ratio of the different sodium salts, the following experiments were undertaken with the assistance of Emil Bräutigam.

An alkali-free garden soil, rich in humus and in calcium carbonate was treated with different quantities of sodium salt solutions. The data are reported in table 4. To test the dissolved organic matter, different methods of determinations were used. As seen in table 4 the quantity of 0.1 *N* $KMnO_4$, necessary for oxidizing the dissolved total organic matter was determined. For this purpose a surplus of the permanganate solution was added to 10 or 20 cc. of the soil solution, at ordinary laboratory temperature; then after boiling, 100 cc. of 2 *N* sulfuric acid and 10 cc. of 0.1 *N* oxalic acid were added.

The latter formed an excess and the resulting solution became colorless; the surplus oxalic acid was then titrated back with the permanganate solution. The amount of permanganate necessary for the oxidizing of the organic matter could thus be determined. The corresponding amounts of oxygen and of

TABLE 4

Influence of salt solutions upon the extraction of organic matter from an alkali-free soil

NUMBER OF EXPERIMENT	QUANTITY OF SOIL USED	AMOUNT AND NATURE OF THE SOLUTION USED	IN 100 CC. OF SOLUTION					COLORIMETRIC VALUES ACCORDING TO LOVIBOND
			Time of revolving	Volume of the solution used for the determination	0.1 *N* permanganate used for oxidation	Corresponding amount of oxygen	Corresponding organic matter	
	gm.		*hrs.*	*cc.*	*cc.*	*mgm.*	*mgm.*	
1	50	500 cc. *N* Na_2CO_3	24	10	18.58	14.98	44.41	95.5
2	50	500 cc. *N* Na_2CO_3	48	10	18.58	14.88	44.41	98.0
3	50	500 cc. *N* Na_2CO_3	120	10	18.58	14.88	44.41	98.0
4	5	500 cc. *N* Na_2CO_3	24	10	3.54	2.80	8.46	9 0
5	50	500 cc. 0.1 *N* Na_2CO_3	24	10	17.70	14.16	42.30	Over 100.5
6	5	500 cc. 0.1 *N* Na_2CO_3	24	10	2.65	2.16	6.33	28.5
7	50	500 cc *N* Na_2SO_4	24	10	2.21	1.76	5.28	6.0
8	50	500 cc. *N* NaCl	24	20	0.88	0.72	2.10	2.5
9	50	500 cc. *N* $NaHCO_3$	24	10	7.69	6.40	19.02	38.0
10	50	250 cc. *N* Na_2CO_3 + 250 cc. *N* NaCl	24	10	12.39	9.92	29.61	67.0
11	50	500 cc. 0.1 *N* $NaHCO_3$	24	10	0.88	0.72	2.10	1.0
12	50	50 cc. *N* Na_2CO_3 + 450 cc. *N* NaCl	24	10	7.04	0.56	16.83	24.0
13	50	50 cc. *N* Na_2CO_3 + 450 cc. *N* Na_2SO_4	24	10	11.10	8.88	26.53	56.0
14	50	250 cc. 0.1 *N* Na_2CO_3 + 250 cc. 0.1 *N* NaCl	24	10	9.77	7.84	23.35	61.0
15	50	250 cc. 0.1 *N* Na_2CO_3 + 250 cc. 0.1 *N* Na_2SO_4	24	10	10.21	8.16	24.40	61.0
16	50	50 cc. 0.1 *N* Na_2CO_3 + 450 cc. 0.1 *N* NaCl	24	10	2.22	1.76	5.31	2.0
17	50	50 cc. 0.1 *N* Na_2CO_3 + 450 cc. 0.1 *N* Na_2SO_4	24	20	0.44	0.32	1.05	2.0

humus were also calculated. In this case 1 cc. of 0.1 *N* $KMnO_4$ was found to correspond to 0.0008 gm. oxygen, or to 0.002385 gm. soluble humus.

The other method of determining the quantity of dissolved humus was the colorimetric method of Lovibond, used in brewery practice. The set of

colored standard glasses compared fairly well with the brown-colored soil solutions. At first glance (table 4) no direct correlation seems to exist between the amount of organic matter and the colorimetric values. This may tend to show that the solvents employed extracted different amounts of colored organic matter. It seems very likely that normal carbonate of soda favored to a high degree the dissolution of dark-colored matter, whereas sodium chloride acted in the opposite manner.

The first three experiments were intended to demonstrate that by treating the soil for 24 hours in a revolving apparatus and then allowing the solution to settle for 48 hours, the equilibrium may be reached. In the corresponding column the time of revolving is given; the time of settling, being equal, was left out of the table. The fourth experiment shows that the smaller the amount of soil used the greater is the amount of dissolved organic matter. The same holds true for experiment 6. The fifth experiment shows that by treating the soil with one-tenth normal sodium carbonate instead of normal solution, the dissolved organic matter hardly differed and the tint of the solution seemed somewhat darker than in the case of the normal solution. Experiments 7, 8, and 9 show that, for the given concentration, the bicarbonate dissolved most, followed by the sulfate, and last by the chloride. But the further examination of the bicarbonate solution was found to contain some normal carbonate, derived from the decomposition of the relatively concentrated solution. In experiment 11, where there was no chance for the decomposition of bicarbonate, the dissolved organic matter was very low and nearly colorless. The other experiments show that the presence of sodium chloride or sulfate, especially in the more dilute concentrations, prevents materially the dissolution of humus. Thus the author's recent experiments seemingly corroborate the theory of Glinka. Nevertheless, practical experiences do not fully agree with the author's idea that in alkali soils the solubility may be solely dependent on the presence of alkaline salts and their relative concentration. A number of alkali soils nearly free from alkaline salts, but rich in soluble humus, could be found. This seems to suggest that here we have to do with a water-soluble humus, which differs in this respect very strikingly from humus of a neutral garden soil, or a "Tschernozem."

Indeed if we treat a neutral prairie soil with normal sodium chloride, until the exchangeable calcium is taken out of the soil, then wash with distilled water, the solution becomes darker, because the calcium cation, which saturated in some way the humus-complex, was exchanged by the sodium cation, giving rise to the formation of humus-dispersoids, or as might be supposed, of sodium-humates, which are likely to be more soluble in water than the calcium-humates. The theoretical question as to whether this might be a purely physical or chemical reaction cannot be discussed further; the fact to be emphasized is that, in alkali soils, the humus might become soluble not only in the presence of normal sodium carbonate, as Glinka suggested, but, if the humus complex is in some respect saturated or changed into a sodium-

humus-complex, this change may convert the insoluble humus into a soluble one. This is done not only by the carbonates of soda, but also by the sulfate or chloride.

Consequently it seems evident that, in alkali soils deficient in carbonate of soda, the humus-complex itself has the nature of changing easily into a colloidal dispersion or true solution, provided only that the concentration of the neutral salts does not reach the limits of coagulation.

Glinka's theory has properly pointed out the difference between the soil-leaching processes in alkaline and acid media, but his discussion treated mostly the humus, the chemical composition of water extracts, and the typical morphology of alkali soils. The latter description was so characteristic, that the similarity between the Russian and the Hungarian alkali soils could easily be recognized. Since many chemical analyses of the Hungarian alkali soils were available, the author was interested to know whether some characteristic differences in the total chemical composition were found by the hydrochloric

TABLE 5

Comparison of the chemical composition of a timber soil and of an alkali soil

HORIZON	TIMBER SOIL		ALKALI	TIMBER SOIL		ALKALI	TIMBER SOIL	ALKALI
	A_1	A_2	A	B_1	B_2	B	C	C
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	0.14	0.28	0.55	0.52	0.32	0.44	0.18	0.71
K_2O	0.50	0.55	0.74	0.54	0.62	1.06	0.74	0.75
CaO	0.25	0.27	2.27	0.41	0.66	5.01	0.49	6.43
MgO	0.52	0.32	1.27	0.47	0.45	1.51	0.77	2.34
Al_2O_3	4.36	7.03	5.17	9.49	10.79	6.31	8.46	7.57
Fe_2O_3	3.54	4.22	4.20	5.17	5.15	3.25	4.30	4.20
CO_2	....	....	1.33	....	....	3.84	....	5.31
SiO_2	3.32	4.62	9.61	4.76	4.61	11.59	6.51	5.48

acid extract of the soil made according to Hilgard. Moreover, the author was engaged at this time (in 1914–1916) in the study of the artificial zeolites, made by the alkaline solution of silicic acid and sodium aluminate (19, 20, 21). The author observed a very similar behavior in the colloidal sodium zeolites and in the alkali soils. The corresponding experiments of the Russian investigator Gedroiz were unknown in international literature, though in 1914, at the meeting of the Second International Soil Commission at Munich, when the chemical methods of soil analysis were treated, the theory of Ganssen on the reconstruction of the soil zeolites, based upon the composition of the hydrochloric acid extract of the soil, as well as the importance of the exchange of bases in soils, was discussed to a large extent. As the Russian investigators did not attend the meeting, however, nobody was informed about the experiments of Gedroiz.

If the chemical composition of a timber soil is compared with that of an

alkali soil in its full profile, some characteristic discrepancy as well as a certain correspondence is found. Robert Ballenegger, a Hungarian soil chemist, studied a typical timber-soil from Tenke (1). The corresponding analytical data of his investigations have been compared in table 5 with those of the author's on the alkali soil profile at Békéscsaba.

If the respective values of the acid and alkali soil profiles are compared, the most striking difference is found in the amount of Na_2O and soluble SiO_2. If horizon C is considered as representing the original regolith, out of which the upper soil-horizons A and B resulted, by processes of weathering and leaching, we might conclude that, in the case of acid-leaching, the silicates of sodium underwent a certain decomposition and washing out from horizon A_1 and A_2, and accumlated in horizon B_2 and B_1. On the contrary, in the alkali soil profile there is no washing out, rather an accumulation of sodium in horizon A,

TABLE 6

Chemical composition of hydrochloric extract of different soil horizons

NUMBER OF SOIL-HORIZON	1	2	3	4	5	6
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	3.90	3.38	2.73	1.26	1.93	2.22
K_2O	0.36	2.01	1.76	1.37	1.42	2.03
CaO	0.36	0.37	0.54	2.09	2.06	2.11
MgO	1.00	1.79	1.42	1.76	1.29	1.91
Fe_2O_3	4.64	6.90	8.38	5.42	5.20	7.42
Al_2O_3	8.20	11.91	10.84	10.22	8.99	14.28
SO_3	0.27	0.28	0.19	0.01	.....	0.03
P_2O_5	0.08	0.08	0.12	0 13	0.12	0.10
CO_2	.....	0.01	0.28	0.14	0.20	0.22
SiO_2	22.76	28.61	23.78	17.78	17.07	27.14
Loss on ignition	5.91	5.98	4.86	5.20	5.19	6.65
Insoluble residue	52.84	39.58	45.15	55.45	56.62	35.99

though the soluble SiO_2 accumulated in horizon B. This might be explained by the supposition that the alkali silicates accumulated in some manner in the alkali soil in the uppermost horizon A. As a similar accumulation of alkali silicates has been found by the author in other alkali soils, a more thorough investigation of the characteristics of alkaline soil weathering and leaching was undertaken in a most typical soil-profile at Hortobagy, one of the largest portions of alkali land in Hungary. Samples were taken in 1914 from the following soil-horizons:

1. Surface-horizon A, eluvial, ash gray colored, total salt content 0.8 to 1.0 per cent, reaction neutral to phenolphthalein; 10 to 30 cm. deep.

2 Horizon B, accumulation horizon, with more or less irregular columnar structure, dark-colored, impervious, very plastic when wet, and cracked when dry. Total salt content 1.0 to 1.2 per cent, neutral.

3. Upper ferruginous horizon, total salt 0.3 to 0.4 per cent, sodium carbonate 0.02 per cent.

4. Calcareous horizon, very hard and rich in concretions. Total salt 0.20 to 0.25 per cent, sodium carbonate 0.03 per cent.

5. Second ferruginous horizon, total salt 0.15 per cent, sodium carbonate 0.02 per cent.

6. Clay underground horizon, somewhat sandy, light blue-gray color, total salt 0.10 to 0.15 per cent, sodium carbonate 0.07 per cent.

The chemical composition of the hydrochloric extract made according to Hilgard is recorded in table 6.[2]

If the insoluble residue is considered, two accumulation horizons are found here—2 and 6. In full harmony with that, two maxima are found for each soluble constituent. It is seen at once, that here again the sodium is concentrated in the uppermost horizon, as in the other alkali soils. It seemed very instructive to separate the whole profile into two parts; the three upper horizons representing a different genesis from the three underlying horizons. We have all evidence to suppose that the alkaline soil-weathering and leaching reached approximately to the fourth horizon, and that beneath, a typical profile of acid soil weathering and leaching is found. The only deviation is found in the CaO-maximum in the fourth horizon which might be easily attributed to the posterior leaching from the alkaline horizons. This statement coincides with the historical fact, that some 100 years ago the whole territory on the Hortobagy was more or less swampy, in other words, under acid soil weathering and leaching conditions. Only later, when the regulating of the Tisza River and the drainage of the inundation territories were begun, did the former swampy lands, by becoming temporarily dry, give rise to the formation of alkali soil.

The chemical characteristics of a soil are seen in a better light when the new terminology of soil analyses[3] is used. A short report in English was published in 1912 (17) and in 1915 (19). The advantage and application of the method were also pointed out. The respective values are summmarized in table 7.

The relatively high amount of the total gram-equivalents of the positive constituents dissolved by the concentrated hydrochloric acid prove that we have to do with a soil-profile of an arid climate, and the fluctuation of these values through the whole profile confirms again the theory that, in the process of leaching of this soil we may assume the presence of two periods. The effect of the earlier leaching period extended down horizon 6, whereas the second leaching period influenced the soil only to horizon 4, the accumulation-horizon of the latter being horizon 2. From the relatively high amount of the soluble silica, we might conclude that the weathering of the mineral part was a very strong one and especially that horizon 2 and 6 are rich in decomposed silicates.

[2] The analysis was made by Geza Binder-Kotrba of this laboratory.

[3] Suggested by the author in 1905, at the meeting of the chemical and mineralogical section of the Hungarian Society of Natural Sciences (13) and in 1909, at the Seventh International Congress of Applied Chemistry in London (15).

We know that the concentrated hydrochloric acid may attack not only the weathered minerals, but also the most unaltered silicates (18, 19), to a smaller degree and only in a highly disintegrate condition. The relatively large amounts of the total gram-equivalents showed at the same time that, although there was a double leaching, the latter was not so effective as in a humid climate, where the total gram-equivalents of the mono- and bivalent positive constituents range around 6 per cent and about 20 per cent in arid soils as in the present case (13,17). The same conclusion may be drawn from the very small portion of carbonate-equivalents.

TABLE 7

Influence of hydrochloric acid upon the displacement of positive and negative ions from the soil

	SOIL HORIZON NUMBER					
	1	2	3	4	5	6
Total positive gm. equivalents, dissolved by conc. HCl in 100 gm. soil	0.8517	1.2124	1.1814	1.0354	0.9531	1.40
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Soluble SiO_2	22.76	28.61	23.78	17.78	17.07	27.14
Insoluble residue	52.48	39.58	45.15	55.45	56.62	35.99
Na^{I}	14.77	8.99	7.45	3.93	6.53	5.11
K^{I}	0.90	3.52	3.16	2.81	3.16	3.07
Ca^{II}	1.51	1.09	1.63	7.20	7.70	5.36
Mg^{II}	5.82	7.32	7.22	8.43	6.72	6.76
Fe^{III}	20.47	21.39	26.66	19.67	20.50	19.89
Al^{III}	56.53	57.69	53.88	57.96	55.39	59.81
SO_4^{II}	0.79	0.57	0.40	0.02	.....	0.05
CO_3^{II}	.....	0.04	1.08	0.62	0.95	0.72
PO_4^{III}	0.39	0.28	0.43	0.53	0.53	0.30
SiO_4^{IV}	98.82	99.11	98.09	98.83	98.52	98.93
Surplus of soluble SiO_2	10.08	10.50	6.31	2.36	2.92	6.23
Total of mono- and bivalent positive constituent equivalents	23.00	20.92	19.46	22.37	24.11	20.30
Total of the trivalent positive constituent equivalents	77.00	79.08	80.54	77.63	75.89	79.70
Total negative equivalents—SiO_4^{IV}	1.18	0.84	1.91	1.17	1.48	1.07

If we now consider the percentage equivalent of the single constituents, we observe that sodium plays the leading rôle, especially in the three upper horizons, whereas the opposite is found in respect to calcium which, accumulating mostly in the lower three horizons, shows at first glance whether in alkali soil, the sodium has taken its place, later exceeding the mono- and bivalent cations ordinarily found in arid soils (13, 17). The author was, at the same time, engaged in the study of some artificial calcium zeolites prepared in the labora-

tory (19, 20, 21). In experimenting with these zeolites, the author observed several times, that the calcium zeolites behaved like a granulated mass, with a good filtering capacity; the respective sodium zeolites, on the contrary, represented a very dispersed and diffusible mass of a bad filtering capacity. As the difference between the two compounds consisted chiefly in the different cations, which could be exchanged very quickly and nearly absolutely by the neutral salt solution of the respective cations, the same process was repeated with some alkali and with some non-alkali soil. The method used for this investigation was a mere provisory one, consisting of the treatment of 50 gm. of air-dry soil with 800 cc. of a 10 per cent solution of ammonium-nitrate. As the alkali soil contained more or less water-soluble alkali salts, another 50-gm. portion of the soil was treated with pure water in the same manner. In table 8 the total amount of the bases determined in the ammonium salt solution is given; in table 9 the data on the water-solution are given; and in table 10 the differences of the two determinations calculated for each hundred grams of air-dry alkali soil of the six horizons of Hortobagy are reported. In the lower part of table 10 the respective values are calculated in millimol-percents.

If the absolute quantities of the exchangeable bases are compared, it becomes evident that the sodium dominates in the upper horizon, and decreases downwards. The calcium on the other hand reaches its maximum in the lowest horizon and gradually decreases toward the upper horizon. It seems very likely, that the sodium cation displaced the calcium cation. As the soil is at the present time infiltrated with sodium salts one is justified in supposing that the soil contains a silicate complex similar to the one prepared by the author under different conditions as well defined artificial zeolites. When these facts were first published (1915) nothing was known of the similar experiments published in Russian by Gedroiz just as that author could not have any idea of the author's Hungarian and German aforcited publications (19, 20, 21). It would be a pleonasm to emphasize intensively the occurrence of this base exchange in alkali soils. If the fact is considered, that three investigators like Gedroiz, Kelley, and the author, very far distant from one another, and under very different conditions, quite independently from one another, and starting from different evidences, concluded in full agreement on the same point; that *in the alkali soils a considerable part of the exchangeable cations is represented by sodium and this combined sodium may be responsible for the bad physical properties of the alkali soil,* it is evident that in this respect the theory of Hilgard again needs some correction, and that the reclamation of alkali lands is not simply a soil-washing process. The theory of Glinka needs also to be corrected in regard to the exceptional rôle of normal sodium carbonate. According to the evidence reported above, *the conversion of a soil into an alkali soil can be done by any neutral sodium salt.*

The author cannot agree with the classification of Gedroiz in regard to the terms saline and alkaline soil. Though chemically true, his distinction does not

TABLE 8

Bases exchanged in 50 gm. of alkali soil by 800 cc. of 10 per cent NH_4NO_3

SOIL HORIZON NUMBER	CaO		MgO		K_2O		Na_2O	
	mgm.	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*
1	73.1	1.30	27.1	9.67	45.1	0.47	298.8	4.81
2	64.6	1.15	162.8	4.03	269.2	2.84	247.2	3.98
3	152.2	2.71	180.1	4.46	196.8	2.08	173.9	2.80
4	275.4	4.90	52.0	1.28	100.3	1.06	88.8	1.43
5	296.8	5.29	127.4	3.15	34.4	0.36	8.4	1.13
6	346.5	6.17	49.3	1.22	84.3	0.89	74.3	1.19

TABLE 9

Amount of water-soluble material in 50 gm. of alkali soil

SOIL HORIZON NUMBER	K_2O		Na_2O		SO_3	
	mgm.	*milli-mol*	*mgm.*	*milli-mol*	*mgm.*	*milli-mol*
1	25.0	0.26	127.9	2.06	48.0	0.59
2	4.8	0.05	153.6	2.47	81.6	1.02
3	180.8	0.91	116.8	1.88	62.4	0.77
4	136.0	1.44	78.4	1.26	32.5	0.40
5	26.2	0.27	6.9	0.11	15.4	0.19
6	56.0	0.59	71.2	1.14	41.6	0.51

TABLE 10

Exchangeable bases in the alkali soil at Hortobágy

SOIL HORIZON NUMBER	CaO	MgO	K_2O	Na_2O	TOTAL
	Milli-mols in 100 gm. of soil				
1	2.60	1.34	0.42	5.50	9.86
2	2.30	8.06	5.58	3.02	18.96
3	5.42	8.92	0.34	1.84	16.52
4	9.80	2.56	.....	0.34	12.70
5	10.58	6.30	0.18	0.04	17.10
6	12.34	2.44	0.60	0.10	15.48
	Milli-mol per cent				
1	26.4	13.5	4.3	55.8	100.0
2	12.1	42.5	29.4	16.0	100.0
3	32.8	54.0	2.0	11.2	100.0
4	77.1	20.0	.....	2.9	100.0
5	61.9	36.8	1.0	0.3	100.0
6	79.7	15.8	3.9	0.6	100.0

point out the fundamental character of all alkali soils—that they are the results of an arid or semiarid climate, and if in some respects they may correspond to the littoral salines, nevertheless, they represent as a whole a different and typical soil type. It is known from the experiments of Hissink that among the saline marsh lands soil layers similar to the true alkali soils are found. He found also that, in this case, the amount of exchangeable sodium becomes rather high in comparison with the other polders,[4] but the polder soil has its own character whether it is a saline or not; although it always represents *an unsaturated soil* as a result of the *soil-weathering in an acid medium* and under *permanent abundance of humidity*. On the contrary *an alkali soil, if truly alkaline or saline, is always the result of a greater or less accumulation of the monovalent cations;* it gives a *higher saturated condition* to the whole soil profile even in the case shown above, when the earlier period of the soil-forming conditions favored an acid weathering and leaching. The question of the degree of saturation of the different soil types will be treated in a later report, as the author is not now able to give exact empirical data on the full question under consideration. But principally the author cannot agree with any conception whereby some single horizons or layers are taken out of the soil profile and treated as some typical soil. That is the great merit of the Russian agronomists who have proved that *for the proper characterization of a soil or even of a soil type, it is not enough to study the surface or any other single horizon of the* soil profile, but the genesis of the whole profile must be considered always. According to the definition of Gedroiz it is possible that the surface horizon of a soil profile might be alkaline, and a lower horizon of the same soil profile might be classified as a saline, and that another horizon of the same profile might be characterized as alkaline-saline. Therefore, it seems better to *reserve the term "alkali soil" for a distinction of the terrestrial salty soils resulting from an alkali medium in the above sense, i.e., under soil conditions of temporary abundance of humidity*, as pointed out by Glinka and the author. On the other hand the term "saline soil" is applied to soils infiltrated for some reason, with a salt solution, independently of the climatic and genetic soil conditions. In this definition the latter has a general and a broader sense than the term "alkali soil," which represents but a typical class of the saline soils in dry climates. This is also in full agreement with the original definition of Hilgard, the author of this term; but this terminology does not interfere with the genetic consideration of the whole soil profile, the characteristics of which were exemplified by that of the alkali soil at Hortobagy.

As a check, the same experiments were carried out with a soil at Keszthely. The total analysis of the hydrochloric soil extract made according to Hilgard is given in table 11. It might be stated that, as a whole, sodium plays a very inferior, almost negligible rôle, in the full profile. The gradual decrease in insoluble residue indicates that the mineral matters decomposable by strong

[4] *Polder* is a littoral endiked soil in Holland, but not marshland, formed by cultivation and soil-washing of the salty "Uvelder" soils.

TABLE 11

Results of analysis of hydrochloric acid extract of the soil at Keszthely

NUMBER AND DEPTH OF THE SOIL HORIZON	1 0 TO 25 CM.	2 25 TO 50 CM.	3 50 TO 60 CM.	4 60 TO 70 CM.	5 70 TO 150 CM.
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Na_2O	0.19	0.26	0.19	0.08	0.18
K_2O	1.49	1.46	1.26	1.62	0.96
CaO	4.23	2.27	2.30	9.68	19.46
MgO	2.19	2.28	2.00	2.80	6.28
Fe_2O_3	3.90	4.26	3.62	3.11	2.27
Al_2O_3	5.58	9.64	11.95	13.19	8.55
SO_3	0.04	0.06	0.05	0.06	0.03
P_2O_5	0.22	0.27	0.19	0.12	0.12
CO_2	1.94	3.64	3.94	10.51	21.86
SiO_2 soluble	17.29	19.92	22.69	19.53	12.28
Loss on ignition	5.39	1.77	3.85	2.63	.....
Insoluble residue	56.56	53.98	47.82	36.86	27.69
Total	99.02	99.81	99.86	100.19	99.68

TABLE 12

Influence of hydrochloric acid upon the displacement of positive and negative ions from the soil at Keszthely

	SOIL HORIZON NUMBER				
	1	2	3	4	5
Total of the positive gram equivalents, dissolved by conc. HCl in 100 gm. of soil	682.15	959.50	1051.90	1412.42	1618.85
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Soluble SiO_2	17.29	19.92	22.69	19.53	12.28
Insoluble residue	56.56	53.98	47.82	36.86	27.69
Na^{I}	0.90	0.86	0.58	0.18	0.34
K^{I}	4.63	3.23	2.54	2.44	1.27
Ca^{II}	22.11	8.44	7.80	24.43	42.80
Mg^{II}	2.83	11.78	9.43	9.83	19.25
Fe^{III}	21.49	16.69	12.93	8.28	5.28
Al^{III}	48.04	59.00	66.72	54.84	31.03
SO_4^{II}	0.14	0.15	0.12	0.11	0.05
CO_3^{II}	1.39	1.21	0.78	0.37	0.32
PO_4^{III}	12.51	16.69	16.47	32.73	59.40
SiO_4^{IV}	85.96	81.95	82.63	66.79	40.23
Surplus of soluble SiO_2	8.45	8.07	9.59	5.31	2.46
Total of the mono- and bivalent positive constituent equivalents	30.47	24.31	20.35	36.88	63.69
Total of the trivalent positive constituent equivalents	69.53	75.69	79.65	63.12	36.31
Total negative equivalents—SiO_4^{IV}	14.04	18.05	17.37	33.21	59.77

HCl, though very high in amount, were leached out of the upper soil horizon. The chemical characteristics of this profile according to the author's system are given in table 12.

The high amount of the total equivalents places the soil among those of arid climate, though all evidences point to the fact that in the earlier period of soil formation there was a time when the climate was more wet, and that this resulted in the washing down of the bivalent cations. This is generally the case in forest soils, and it is very likely that originally this land was overgrown with wood. After the soil was cultivated surface evaporation gave the more mobile soil constituents opportunity to migrate to the surface. Indeed a marked accumulation of sodium, potassium, and calcium equivalents characteristic of arid soils is found in the surface horizons. We see here again a certain similarity to the origin of the alkali soil at Hortobagy, with the only

TABLE 13

Exchangeable bases in the soil at Keszthely

SOIL HORIZON NUMBER	CaO	MgO	K_2O	Na_2O	TOTAL
	Milli-mols in 100 gm. of soil				
1	14.84	0.96	0.152	0.376	16.328
2	13.64	0.54	0.134	0.408	14.678
3	16.58	2.42	0.158	0.066	19.224
4	14.16	2.50	0.108	0.344	16.932
5	12.86	0.72	0.204	0.222	14.006
	Milli-mol per cent				
1	90.88	5.87	0.93	2.30	100
2	92.92	3.67	0.91	2.75	100
3	86.24	12.58	0.82	0.34	100
4	83.74	14.76	0.63	2.03	100
5	91.81	5.14	1.45	1.58	100

difference that, in the latter case, the second period was arid, but intersected with temporary humid soil conditions, and that this resulted in the formation of a typical alkali soil profile; on the other hand, in the case of the soil at Keszthely, the earlier humid period was succeeded by an artificial dry period that resulted from bringing under cultivation the former forest land. It is easy to understand that destroying the forest and turning it over to regular agriculture, favor surface evaporation, which goes hand in hand with the accumulation of the more mobile soil constituents.

The exchangeable bases were determined as previously, and the respective data are given in table 13.[5]

If these data are compared with those in table 10, the conclusions may be

[5] The determinations were made by the author's former assistants Stephen Száraz and Coloman Gehring.

drawn in the case of the soil at Keszthely, that the leading exchangeable cation over the whole profile is calcium, figuring the millimol percentage at an approximate value of 83 to 93, the magnesium coming second but with a much smaller value, and potassium and sodium representing hardly 1 or 2 per cent. Here we have just the opposite from that found in the profile of the alkali soil, where the calcium was gradually displaced by sodium then by potassium and magnesium.

When the author first obtained these results in 1915, he did not know of the investigations of Hissink, Gedroiz, and Kelley on the exchangeable cations in

TABLE 14

Exchangeable bases in the soils

SOIL QUALITY		CaO	MgO	K_2O	Na_2O	TOTAL
		Milli-mols in 100 gm. of soil				
Bad alkali, impermeable	Hortobágy 1	2.60	1.34	0.94	9.62	14.50
	Békéscsaba 5	8.32	3.86	0.14	7.30	19.62
	Mezöhegyes	17.65	2.54	0.55	4.68	25.42
Mild alkali permeable	Békéscsaba 1	13.58	5.18	0.44	.....	19.20
	Békéscsaba 2	11.22	2.32	0.50	.....	14.04
	Békéscsaba 11	11.94	4.16	0.72	0.16	16.98
Non-alkali permeable	Keszthely 1	15.96	1.75	0.33	0.19	18.23
	Keszthely 22	15.18	1.82	0.41	0.12	17.53
		Milli-mol per cent				
Bad alkali impermeable	Hortobágy 1	17.93	9.24	6.48	66.35	100
	Békéscsaba 5	42.41	19.67	0.71	37.21	100
	Mezöhegyes	69.43	10.00	2.16	18.41	100
Mild alkali permeable	Békéscsaba 1	70.73	26.98	2.29	.....	100
	Békéscsaba 2	79.92	16.52	3.56	.....	100
	Békéscsaba 11	70.32	24.50	4.24	0.94	100
Non-alkali permeable	Keszthely 1	87.56	9.61	1.82	1.01	100
	Keszthely 22	86.55	10.38	2.36	0.41	100

neutral and acid soils, (2, 3, 6, 7, 8, 9, 10). His own original publications in Hungarian date back to 1917. In the author's inaugural dissertation in 1916, at the Academy of Sciences at Budapest and at the meeting of the chemical and mineralogical Section of the Hungarian Society of Natural Sciences, he reviewed his first experiments in this field, showing some characteristic evidences between the permeability of different soils and the relative amount of different exchangeable cations (19, 20). The respective values are given in table 14.

Among the soils of a bad filtering capacity, a gradual displacement of calcium by sodium is found, whereas in the case of good permeability, even if the soil itself may be of an alkali character, the relative value of the sodium millimols among the exchangeable bases seems to be quite negligible. This fact was indeed the starting point of the author's further studies in that line. At that time the experiments of Hissink and of Kelley (6, 10) were not yet published, and those of Gedroiz in Russian were unavailable. It is true, on the other hand, that the author's publications in Hungarian were useless to the aforementioned investigators. After all, there is now plenty of evidence to show that the dominant rôle of the exchangeable calcium in neutral and acid soils, and also of the fact that, in the case of alkali soils, its place may be taken partly or fully by the cation sodium.

The author does not intend further to discuss here the principal question: *whether the displacing of these cations represents a true chemical reaction.* Based on his experiments on the artificial zeolites, and various other investigations, not yet published, the author is inclined toward the chemical explanation of this phenomenon; he hopes to be able to give a detailed confirmation of this view in the near future.

In summing up the theory of the origin of alkali soils, it may be stated that *alkali soils may originate under arid and semiarid conditions, where in the past there is in the soil a temporary abundance of humidity intersected by dry periods.* In the case of the Hungarian alkali lands that this was effected is historically indicated by the large inundational territories of earlier times, resulting partly in swampy and peaty lands and partly in alkali soils. Another combination of favorable conditions for the origin of alkali soils was the collection of seepage water in the lower basins and water rivulets in the large sandy territory between the two main rivers, the Danube and the Tisza (Theiss), the bottom of these lowlands being always impervious clay or calcareous hardpan. In both cases there was an opportunity for the sodium salts to accumulate on the surface, and *the more or less concentrated sodium salt solutions reacted with the zeolite-humate-complex in the soil in replacing in some degree the calcium, magnesium, and potassium by the sodium cation.* The degree of this replacement was different according to local circumstances; it was evidently dependent not only on the concentration of the same solution lodging in the soil repeatedly but, also on the fact that the ratio of the cations in the solution, and the original composition of the solid phase of the soil might regulate the equilibrium of the whole reaction, which according to Ramann (11) *follows the law of mass action.* As far as the genesis of the alkali soils in other parts of the world can be observed, similar considerations can be traced. It is hoped that the close coöperation of the numerous investigators engaged in this line of work will insure quicker solution of the problem. In this respect the author should like to open here the discussion on the origin of the different alkali soils of the world. The discussion should treat the following questions:

1. Is it right to generalize the thesis that, for the formation of alkali soils, in the above sense, three factors are responsible; namely, arid or semiarid climate, an impervious subsoil or hardpan, and temporary abundance of humidity in the soil, intersected with dry periods?

2. Is it right to treat the alkali soils as soils in which the exchangeable sodium becomes to some extent a ruling factor, or may it not be that in some cases, other cations, like potassium, and magnesium are displacing to a more or less degree the exchangeable calcium?

3. What is the typical morphological and chemical character, in the above discussed sense, of the typical alkali soil profiles in different parts of the world? Which factors of the soil formation may chiefly influence this evolution?

As the salty soils of humid climate are of different origin, but have some resemblance in their chemical and physical character, they should be treated under a separate heading.

REFERENCES

(1) BALLENEGGER, R. 1917 Contribution to the chemical composition of Hungarian soils. [In Hungarian.] *Ann. Hungarian Roy. Geol. Inst.* (1916).

(2) GEDROIZ, K. K. 1914 Die Kolloid-chemie in Fragen der Bodenkunde. *Zhur. Opytn. Agron.* 15: 181–216.

(3) GEDROIZ, K. K. 1916 Pouvoir absorbant du sol et les bases zeolitiques des sols. *Zhur. Opytn. Agron.* 17: 472–528.

(4) GLINKA, K. 1914 Die Typen der Bodenbildung, p. 177–213. Berlin.

(5) HILGARD, E. W. 1910 Soils, p. 422–549. New York.

(6) HISSINK, D. J. 1922 Beitrag zur Kenntnis der Adsorptionsvorgänge im Boden. *Internatl. Mitt. Bodenk.* 12: 81.

(7) HISSINK, D. J. 1925 Der Sättigungszustand des Bodens. *Ztschr. Pflanzenernähr. u. Düngung.* 4 (A): 137–158.

(8) HISSINK, D. J. 1925 Base exchange in soils. *Trans. Faraday Soc.* 20: 550–566.

(9) KELLEY, W. P., AND CUMMINS, A. B. 1923 The formation of sodium carbonate in Soils. Cal. Agr. Exp. Sta. Tech. Paper 3.

(10) KELLEY, W. P., AND BROWN, M. S. 1924 Replaceable bases in soils. Cal. Agr. Exp. Sta. Tech. Paper 15.

(11) RAMANN, E., AND SPENGEL, A. 1918 Zur Kenntniss der Bodensorption. *Landw. Vers. Sta.* 92: 127.

(12) DE'SIGMOND, A. A. J. 1905 Study on the "Szik"-Soils. (Third publication on this matter.) Pub. Hungarian State Exp. Sta. "Kisérletügyi Körleményck" 8 (3). [In Hungarian.]

(13) DE'SIGMOND, A. A. J. 1905 A new method in the interpretation of the chemical composition of minerals and soils. [In Hungarian.] *Magy. Chem. Folyóirat (Hungarian Chem. Jour.)* 13 (11–12).

(14) DE'SIGMOND, A. A. J. 1909 Über die Bedeutung der chemischen Bodenuntersuchungen im Gebiete der Agrogeologie. (Compt. rend. de la première Confer. Internatl. d'Agrogeology, Budapest.)

(15) DE'SIGMOND, A. A. J. 1909 Contribution to the unification of terms in soil and mineral analysis. Proc. Tenth Internatl. Cong. Appl. Chem., Sect. 7. London.

(16) DE'SIGMOND, A. A. J. 1911 Erfahrungen über die Verbesserung von Alkaliböden. *Internatl. Mitt. Bodenk.* 1:44–66.

(17) DE'SIGMOND, A. A. J. 1912 Introduction of a new terminology in indicating the chemical composition of minerals and soils. *Internatl. Mitt. Bodenk.* 2: 190–203.

(18) DE'SIGMOND, A. A. J. 1914 Bericht über die Arbeiten der Internationalen Kommission für die chemische Bodenanalyse. *Internatl. Mitt. Bodenk.* 4: 271–279.

(19) DE'SIGMOND, A. A. J. 1915 Ueber die Charakterisierung des Bodens auf Grund des salzsauren Bodenauszuges und des Basenaustauschvermögens. *Internatl. Mitt. Bodenk.* 5: 164–224.

(20) DE'SIGMOND, A. A. J. 1916 On the production of artificial zeolites, their composition, properties and importance in respect to Soil Science. [In Hungarian.] *Math. Term. Tud. Értesitö.* 34: 279–315.

(21) DE'SIGMOND, A. A. J. 1916 The chemical and physical properties of the artificial zeolites. [In Hungarian.] *Magy. Chem. Folyóirat* [*Hungarian Chem. Jour.*] 22 (9–11).

(22) DE'SIGMOND, A. A. J. 1923 Monograph on the "Szik"-Soils of Hungary and their reclamation. [In Hungarian.] Budapest.

(23) DE'SIGMOND, A. A. J. 1924 The Alkali Soils in Hungary and their Reclamation. *Soil Sci.* 18: 379–381

PLATE 1

DISTRIBUTION OF THE TOTAL SALTS TO AN AVERAGE DEPTH OF 120 CM. ON ALKALI LAND

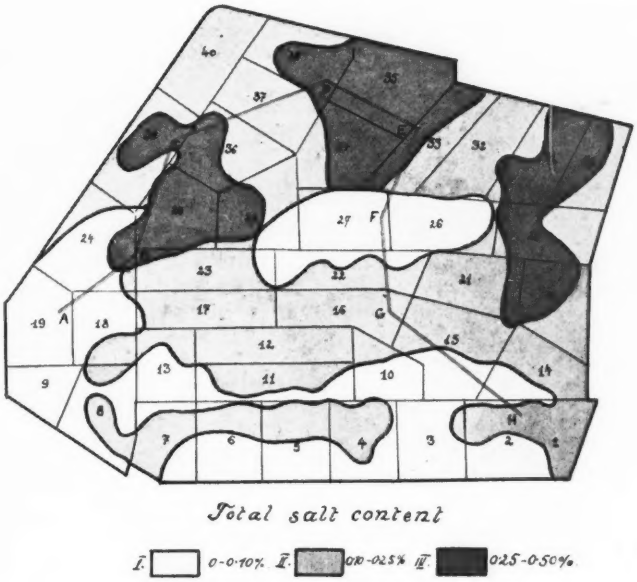

40
37
35
34
33
32
27
F
26
24
23
22
21
19
A
18
17
16
G
15
12
14
13
11
10
9
8
H
7
6
5
4
3
2
1
Total salt content
I. 0-0·10%
II. 0·10-0·25%
III. 0·25-0·50%

PLATE 2

FIG. 1. How the vertical distribution of the four typical soil-horizons fluctuates in a cross-section through the different salt classes, along the line ABCDEFGH shown in plate 1.

FIG. 2. Corresponding salt content of the four soil-horizons of figure 1.

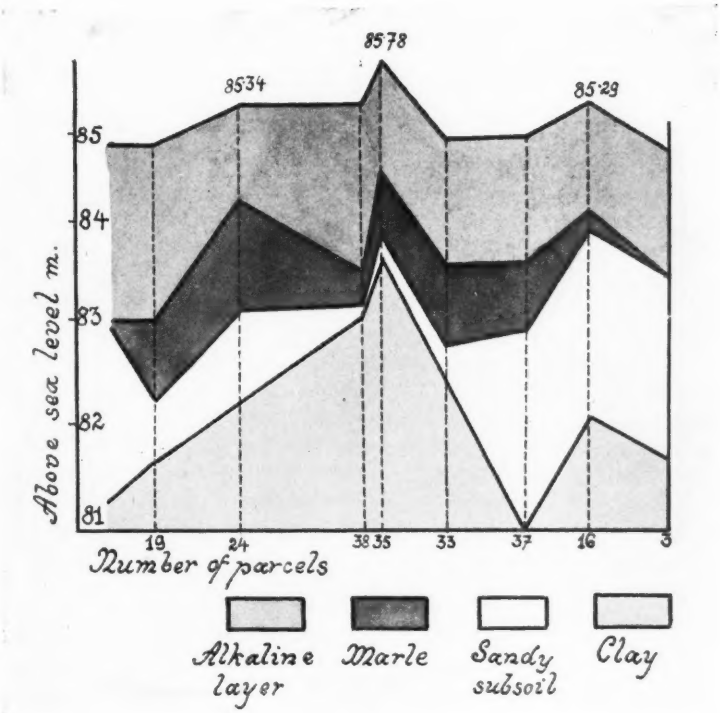

85·78
85·34
85·29
85
84
83
82
81
Above sea level m.
19
24
38
35
33
37
16
3
Number of parcels
Alkaline layer
Marle
Sandy subsoil
Clay

FIG. 1

Total salt
Sodium carbonate
0·375
0·236
0·180
0·065
0·013

FIG. 2

DO COLLOIDS EXIST AS A COATING AROUND THE SOIL GRAINS

GEORGE JOHN BOUYOUCOS

Michigan State Agricultural Experiment Station

Received for publication December 7, 1925

It appears to be the general belief that the colloids in the soil exist as a coating around the soil grains or as an encasing gel (2, 4, 6). As the subject, however, seems never to have received a direct and purposeful study, this belief is founded more on supposition than on experimental facts. This supposition was probably based upon the old idea that the colloidal matter in the soil was small, rarely over 1.5 per cent according to the claims of Schloesing (7) which persisted until recently. The inference was logical, therefore, that this small amount of colloidal matter would be spread as a coating around the soil grains. Recent studies (1, 3) have revealed, however, that the colloidal content of soils is very large, amounting to more than 70 per cent in many typical heavy clays, more than 50 per cent in some clay loams, and more than 15 per cent even in typical sandy loams. It becomes at once apparent, therefore, that all this colloidal mass cannot exist entirely as a coating around the soil grains, especially in the clays and clay loams. In view of these new revelations, it is of considerable interest and importance to ascertain how the colloidal complex really exists in the soil. It is the object of this paper, therefore, to present data bearing on the subject. It must be stated at the outset, however, that the subject presents many difficulties in the way of arriving at an absolute conclusion as to the actual constitution of the colloidal material in the soil, but the observations and experimental data presented herewith tend to throw much light on the subject.

EXPERIMENTAL

The problem has been studied principally by two different methods: first, by optical examination; and secondly, by the heat of wetting method.

Optical Examination

The soils were examined both by the naked eye and under the microscope. Both types of examinations revealed the fact that the coarse soil material, such as the gravel and the coarse and some of the fine sand, was not always encased in a coating of colloidal material. On the contrary, in almost all the mucks and peats examined in dry condition, the sand present was clean. When a wet block of muck or peat was allowed to dry intact, the sand particles could easily be seen with the naked eye enmeshed in or stuck to the or-

ganic material or colloid, but upon gentle crumbling of the blocks, the sand particles would fall apart as independent material and with a clean surface. On the surface of mucks and peats in the field the clean sand particles could readily be seen shining.

The optical examination of the mineral soils revealed, in general, the same facts as in the case of the organic soils. In sandy soils the larger sand particles could be readily seen, even with the naked eye, to be mostly bare and not covered with a coating of gel. In some cases these larger sand particles were covered with a coating, which would come off on the slightest rubbing between the fingers, indicating that the force with which a coating may be held around a sand particle is probably not very great. Sand particles small enough to pass a 100-mesh sieve could be readily seen to be bare and with a white surface.

In the heavier classes of soils—including the loams, the silts and the clays, most of the gravel, and the large and medium sands—the solid particles also appeared practically devoid of a gel coating. Whatever coating they did have, came off rather readily. When these soils were allowed to dry in solid masses and were then broken in two or more pieces, the gravel and the sand could be easily seen on the broken sides sticking to the mass and would come off rather easily and bare. Where the solid particles were extremely fine and the amount present was not so large as in clays, they were not so apparent to the naked eye but under the microscope they could be seen in most cases.

These find sand particles were more or less completely enmeshed in the clay or colloidal material, but, as will be shown subsequently, even under these conditions they also tended to fall apart more or less independently of the colloidal material.

Heat of wetting

The observations made under the optical examination were tested by means of the heat of wetting method. It was reasoned that if the sand particles were more or less devoid of a colloidal coating, their heat of wetting ought to be very low. The difficult problem that presented itself, however, was how to separate the sand particles from the colloidal material or from the rest of the soil mass. Two procedures were attempted: one consisted of picking out, by means of forceps, the sand particles that were visible to the naked eye, and the other, of sieving the soils. The first method was practical and quite satisfactory with the sands, sandy loams, loams, and clay loams, but not always with the heavy clays or soils in which the sand particles were extremely small and dust covered. With the second method, the soil was sieved without grinding, if possible, and where necessary the soil mass was crumbled gently. Soils taken from the surface field were first allowed to dry and then were passed through a 10-mesh sieve to separate them from stones and gravel. The soils that were dried hard were either pressed with the hand on the 10-mesh sieve until they crumbled and went through it or they were broken up in a mortar

into crumbles. After a soil had passed a 10-mesh sieve it was well mixed and then sieved through a 200-mesh sieve. The material that went through the 200-mesh and that which remained behind were considered different and their heats of wetting were determined. Table 1 contains the results obtained on the sand particles picked out with forceps and table 2 contains the results on the soils sieved.

TABLE 1

Heat of wetting of picked sand particles from different soils

	CALORIES PER GRAM
Norfolk sandy loam	0.13
Fresno fine sandy loam	0.10
Corville sandy loam	0.11
Chester loam	0.19
Crowly silt loam	0.12
Amarillo fine sandy loam	0.21
Rhode Island sandy loam	0.10
Pennsylvania silt loam	0.11
Tennessee silt loam	0.15
Michigan clay loam	0.16
Illinois black clay loam	0.23

TABLE 2

Heats of wetting of material passing 200-mesh sieve and of that remaining behind

	SOILS	MATERIAL PASSING 200-MESH SIEVE	MATERIAL REMAINING BEHIND
		calories per gram	*calories per gram*
1	Norfolk sandy loam	3.94	2.05
2	Fresno fine sandy loam	1.32	0.92
3	Corville sandy loam	1.03	0.57
4	Amarillo fine sandy loam	6.54	3.41
5	Rhode Island sandy loam	2.78	2.47
6	Pennsylvania silt loam	2.54	3.09
7	Ohio silt loam	2.07	2.35
8	Michigan clay loam	4.05	4.98
9	Illinois clay loam	3.24	4.04
10	Michigan Ontonagon clay loam A_1	3.74	4.14
11	Michigan Ontonagon clay loam A_2	3.51	4.95
12	Michigan Ontonagon clay loam B_1	6.30	6.92
13	Red clay	2.30	3.41
14	California adobe clay	5.70	6.20

An examination of the results in table 1 shows immediately that the heat of wetting of the sand particles which can be easily separated from the soils, is practically negligible, which goes to prove that these sand particles have practically no colloidal coatings around them. The slight heat of wetting that is

shown is due mainly to the dust of the finer material adhering to their surfaces, and also to some soil particles taken in by mistake because of the difficulty of separation. If it were not for these two latter factors, the heat of wetting would have been nil, almost the same as that of quartz sand. The conclusion of these results would seem to be, therefore, that as a general rule the gravel, the large sands, and in some cases the fine sands, either are not covered or do not stay permanently covered with a colloidal coating. There are undoubtedly exceptions, but in general this conclusion would hold.

The results in table 2, show that with the exception of three cases out of fourteen, the heat of wetting of the material that went through the 200-mesh sieve is greater than that which remained behind. In other words, the material that remained behind in the 200-mesh sieve, and contained in many cases the gravel and the coarse sand, gave a higher heat of wetting than the fine material that could pass the 200-mesh sieve, except in the three cases mentioned. The difference in some cases is quite appreciable; for instance, on Ontonagon clay loam A_2 the 200-mesh sieved material gave a heat of wetting of 3.51 calories per gram as against 4.95 calories of the coarse material. In red clay the heat of wetting was 2.30 calories for the fine material and 3.41 calories for the coarse material. The remarkable thing is that the coarse material in some soils, as in Rhode Island sandy loam, contains as much as 25 per cent of coarse gravel and sand which itself had no heat of wetting, and yet the total coarse material gave a higher heat of wetting than the fine which went through the 200-mesh sieve.

The question now is, how can these results be explained. For one thing it is very apparent that the coarse material contains more colloids than the fine material which goes through the 200-mesh sieve. This conclusion seems inevitable because, as has been previously shown (1), it is the colloidal material which is mainly responsible for the heat of wetting. The fine material, therefore, contains a greater proportion of non-colloidal substance, mainly very fine sand, than the coarse portion even though the latter also contains the gravel and the coarse sand, but the larger proportion of colloid out-weighs these coarser substances.

In reference to the constitution of the colloidal material in soils, these results can be most reasonably explained on the hypothesis either that the colloids in the soil do not exist wholly or permanently as a coating around even the small grains, or that they are evenly distributed around the soil grains or throughout the soil mass. If the colloids existed as a coating around the soil grains, especially the smallest, then the fine material which went through the 200-mesh sieve certainly ought to contain more colloids and should give a higher heat of wetting.

The most logical hypothesis under which these results can be explained is that the colloids in the soil exist partly as a coating and partly as an independent component containing various amounts of impurities. Which of these two forms will predominate will depend upon the soil or upon the total

colloidal content present. In the sands, the coating form should be expected to predominate, but because of the poor adhesion between the surfaces of the sand and the colloidal coatings, the latter tend to break off easily under tillage process. In the sandy loams, loams, silts, and clays, the colloids as an independent component would tend to predominate. In these soils there may be compound particles which are composed largely of colloidal material, and which, because of the great adhesive—cohesive and cementing forces of the colloidal particles, are hard and almost unbreakable when dry.

The results obtained on the heat of wetting of the fine and coarse material as already considered, fit very well the above hypothesis, and are explainable by it. For instance, the reason that the coarse material gives a higher heat of wetting than the fine material which passes the 200-mesh sieve is because the coarse material contains a large portion of the colloids as an independent component or as compound colloidal particles. These compound colloidal particles together with that portion of the colloids which may exist as a coating give the coarse material a higher percentage of colloidal material than they do the fine material. Since large portions of the colloids exist as compound particles and are quite obdurate to breaking they do not pass through the 200-mesh sieve. The fine material that passes the 200-mesh sieve is composed of very fine sand, more or less coated with colloids, of some silt, and of some colloidal dust. The colloidal dust does not predominate in the fine material as do the colloidal compounds in the coarse material, and consequently the heat of wetting in the former is less than in the latter. Considering that the fine sand and silt passing the 200-mesh sieve present an enormous surface, it becomes evident that if this surface was well coated with colloids, the heat of wetting should be much greater in the fine than in the coarse material.

The above hypothesis also tends to explain the results that are exceptions to the general trend. Table 2 shows that the three exceptions of a greater heat of wetting in the fine than in the coarse material, are confined to the sandy soils. It was stated above that the adhesive forces between the surfaces of the sands and the colloids are not so great as the cohesive forces of the colloidal particles. The colloidal coating of the sand particles, therefore, can easily break off and if in a thin layer, will crumble into fine particles on slight disturbance. When these sandy soils, therefore, are sieved, the fine colloidal particles will pass through, and the proportion of the colloids to the fine sand that also went through the sieve, is greater than that of the colloids to the sand remaining behind. The result is that the fine material has a higher heat of wetting than the coarse, as the results show.

It might be argued that the difference in the heat of wetting of the fine and coarse material as separated by the sieve does not prove that all the colloids are not present in the soil as a coating around the soil particles, because in the handling and preparation of the soil for sieving, the colloidal coating could break off or crack from the soil grains and thus give the results obtained. The answer to this argument is that all the handling or treatment that most of the

soils employed received, was merely putting them in the sieve and shaking them gently. But the results of the soils that were merely gently sieved are the same as those where the soils were ground to crumbs. So it does not appear that the handling of the soils is responsible for the type of results obtained.

That the colloidal content of the soils may not and cannot all exist as a coating around the soil grains, is supported very forcibly by the mode of occurrence and the amount of colloids in the soil.

A comprehensive consideration of the actual occurrence of the colloids in the soil reveals immediately the fact that they do not remain where they are formed—in the most rapidly weathering zones of the earth crust. In the humic regions, they have a tendency to move downward with the percolating water, and to concentrate at certain zones or subsoils, so that the latter almost always contain more colloids than the surface soil. It is very well known, of course, that when the colloids are dispersed, as they are by repeated washing or by other treatments, they will pass through even a very fine filtering medium, such as filter paper. The colloids from the surface soils, therefore, as a pure colloid can easily pass through a column of soil and concentrate in the subsoil or B horizon. When they concentrate at the lower horizons, they can do so in an irregular manner: in the capillary channels of the soil, at the edges of particles, etc. These percolating colloids do not necessarily concentrate, therefore, around the soil grains with the latter as a nucleus. Even in the ideal cases where it is imagined that the colloid gel is formed around the original mineral particle by the decomposition and hydrolyses process, it cannot be said that this gel will premanently stay there. It must always be remembered that the soil is a dynamic and not a static system.

The clays which are nearly all colloids (1, 5) are formed principally under still water. The non-colloidal and some colloidal material will settle first and the purer colloidal last. This last colloidal material certainly does not exist as a coating. If this clay soil should be put under cultivation, it is not reasonable to suppose that the colloidal part will be finally distributed as a coating around the soil grains, especially when it is remembered that the colloids exist in the soil not as sol but almost wholly as gel.

SUMMARY

A study has been made to determine the constitution of the colloids in the soil. The old idea has been that the colloidal content of the soils exists entirely as a coating around the soil grains. This idea probably originated from the old belief that the colloidal content of soils was rarely more than 1.5 per cent. We now know, however, that the amount of colloids in the average soil is more than 70 per cent in many cases.

The experimental results presented in the foregoing study indicate that the colloids in the soil do not exist entirely as a coating around the soil grains, but also as an independent component, either pure or containing different amount of impurities and scattered irregularly throughout the soil mass.

The experimental results and conclusions are strongly supported by a logical consideration of the form and amount of the colloids present in the soil.

Optical examination of soils shows that they contain particles of sand and pebbles of various sizes which are not covered with colloidal gel.

The soil material that goes through 200- and 325-mesh sieves, is not clay. As a rule it contains less clay and colloids than the coarse material remaining behind.

REFERENCES

(1) Bouyoucos, G. J. 1925 Heat of wetting as a new means of estimating the colloidal material in soil. *Soil Sci.* 19: 153–162.

(2) Cameron, F. K. 1911 The Soil Solution, p. 36. Easton, Pa.

(3) Gile, P. L. et al. 1924 Estimation of colloidal material in soils by adsorption. U. S. Dept. Agr. Bul. 1193.

(4) Gordon, N. E. 1925 The theory of adsorption and soil gels. *Colloid Symposium Monog.* 2: 114–125.

(5) Josph, A. F. 1925 Clay as soil colloids. *Soil Sci.* 20: 89–94.

(6) Keen, B. A. 1920 Relations existing between the soil and its water content. *Jour. Agr. Sci.* 10: 44–71.

(7) Schloesing, T. 1874 Determination de l'argile dans la terre arable. *Compt. Rend. Acad. Sci.* [Paris] 78: 1276–1279.

RELATION OF FINENESS OF GRINDING TO RATE OF SULFUR OXIDATION IN SOILS[1]

R. E. STEPHENSON

Oregon Agricultural Experiment Station

Received for publication December 26, 1925

Sulfur as brought from the mine in the crude state by the Frash hot-water process, when cool remains in the lump form. For agricultural use, and especially for use on soils, the crude lump which is usually more than 99 per cent pure, is ground into different grades according to fineness, the very finely ground, being known as "flour sulfur." Since the more finely the sulfur is ground, the more expensive is the process, if coarser material is sufficiently effective, a coarser grinding of sulfur used on soils would be economical.

For many uses also the crude lump sulfur instead of being ground, is melted and distilled for purification. The distillate may be cooled and collected by a certain process in the form of very fine particles, and is known as "flowers of sulfur," or it may be cooled en masse, later to be broken up and ground as in the case of the crude sulfur. The refined and purified sulfur is of course more expensive than the crude sulfur, regardless of grinding, and perhaps is no more effective on the soil.

In this study, different grades of crude sulfur, according to fineness of grinding, were compared. Refined flour sulfur, as well as a composite sample with all degrees of fineness of the crude were also used. The chief study was to determine the rate of oxidation.

Three soils were used in the study, all rather coarse in texture and carrying a good proportion of sand, as is characteristic of areas of light rainfall. Soil 1 is known as Redmond sandy loam and is characteristic of Eastern Oregon soils. Soil 2 is a sandy loam from Klamath Falls, and is characteristic of Southeastern Oregon soils. Soil 3 is a Columbia fine sandy loam from Grants Pass, and is typical of Southern Oregon soils. All the soils are nearly neutral in reaction and in good physical condition. All are fairly productive soils but respond to the use of sulfur on legumes under field conditions.

[1] The work was started on soil 1 by Messrs. Lance and Higby, who were doing some advanced work in soils under the direction of Prof. C. V. Ruzek. S. C. Lance and W. M. Higby together made the analysis of sulfates for the one soil for one month. School closed at that time and the problem was considered of sufficient importance to be assigned to the author for completion. Two other soils were then taken up and the study completed as herein reported.

Published by permission of the Director of the Oregon Agricultural Experiment Station.

TABLE 1

Amounts of sulfur oxidized to sulfates

In 100 gm. of soil

SULFUR MESH	2 WEEKS			4 WEEKS			7 WEEKS			11 WEEKS			19 WEEKS			FINAL SAMPLING		
	Soil number			Soil number			Soil number			Soil number			Soil number			Soil number		
	1	2	3*	1	2	3*	1	2	3*	1	2	3*	1	2	3*	1	2	3*
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*per cent*	*per cent*	*per cent*
100	0.0090	0.0327	0.0506	0.0131	0.0628	0.0974	0.0810	0.0910	0.1584	0.1119	0.1125	0.2479	0.1329	0.1336	0.2609	86.2	86.7	85.9
80	†	0.0096	0.0280	†	0.0228	0.0439	0.0275	0.0431	0.0895	0.0678	0.0631	0.1381	0.1132	0.0926	0.2538	73.1	59.3	83.8
60	0.0041	0.0077	0.0124	0.0127	0.0144	0.0231	0.0223	0.0272	0.0400	0.0451	0.0332	0.0816	0.0838	0.0521	0.1282	53.5	32.3	42.0
40	0.0036	0.0048	0.0089	0.0036	0.0092	0.0109	0.0111	0.0145	0.0239	0.0224	0.0246	0.0314	0.0486	0.0327	0.0334	30.0	19.4	10.4
20	0.0028	0.0032	0.0051	0.0041	0.0039	0.0046	0.0085	0.0076	0.0085	0.0111	0.0101	0.0127	0.0264	0.0164	0.0168	15.2	8.5	4.9
10	0.0036	0.0027	0.0028	0.0028	0.0021	0.0023	0.0042	0.0042	0.0052	0.0065	0.0062	0.0059	0.0093	0.0064	0.0067	3.8	1.9	1.5
Coarser than 10	†	0.0017	0.0026	0.0028	0.0019	0.0019	0.0042	0.0032	0.0048	0.0050	0.0060	0.0046	0.0058	0.0059	0.0068	1.5	1.5	1.5
Refined flour	†	0.0375	0.0763	0.0094	0.0690	0.1083	0.0660	0.0931	0.1447	0.0996	0.1006	0.1955	0.1150	0.1220	0.2215	74.3	78.9	73.1
Sand sulfur	†	0.0045	0.0081	†	0.0092	0.0117	0.0146	0.0165	0.0203	0.0283	0.0243	0.0276	0.0386	0.0227	0.0265	23.3	12.7	8.1
Check	0.0036	0.0008	0.0021	0.0041	0.0012	0.0010	0.0035	0.0018	0.0028	0.0041	0.0032	0.0026	0.0036	0.0036	0.0022			

* Soil 3 had sulfur at the rate of 2,000 pounds per 2,000,000 pounds of soil instead of 1,000 pounds, which was the rate for soils 1 and 2.

† The blanks represent preliminary work which could not be re-checked.

In this study the soils were incubated in earthenware jars after being treated with the different sulfur separates. On two of the soils, sulfur was applied at the rate of 1,000 pounds per 2,000,000 pounds of soil, and on the other, the rate was doubled. Heavy applications were used in order to obtain differences that could be accurately determined. The moisture was maintained at about optimum, or 20 per cent, and the temperature was that of the laboratory.

The different grades of sulfur used were 100, 80, 60, 40, 20, 10 and coarser than 10 mesh, being compared also with the original sand sulfur or composite, containing all the separates in the following per cents, 10.1, 3.3, 9.5, 13.9, 47.1, 16.0, and 0.1 respectively. These were further compared with refined flour sulfur, all of which passed the 100-mesh sieve.

The test was continued for $5\frac{1}{2}$ months. Samplings were made at intervals of 2, 2, 3, 4, and 8 weeks. The samples were dried and the soluble sulfate was extracted with water, 5 parts of water being used to 1 part of soil. The results represent gravimetric determinations. Table 1 shows the size of sulfur particles, and the amount oxidized to sulfate sulfur at each sampling, and the percentage of sulfur oxidized at the final sampling.

With the exception of a few irregularities, there is a consistent increase in the amount of sulfur oxidized with each successive sampling and a consistent decrease in the amount oxidized with increasing coarseness of grinding. The refined flour sulfur, all of which passed the 100-mesh sieve in every case, failed to oxidize as rapidly as the 100-mesh crude sulfur, and in two cases was not oxidized more rapidly than the 80-mesh crude. There is no apparent reason for more rapid oxidation of the crude sulfur.

Material coarser than 40 mesh oxidized very slowly, whereas material finer than 40 mesh was rather rapidly oxidized. The crude sand sulfur as a composite sample was rather slowly oxidized, no doubt because of the high percentage of the coarser material—nearly two-thirds of the composite is coarser than 40 mesh, and only about one-fourth is finer; the 20-mesh size represents almost half the composite.

In what way sulfur application to the soil in the sections of limited rainfall stimulates the growth of legumes is not definitely known. It has been postulated that the sulfuric acid produced brings plant nutrients, and especially calcium, into solution and is for that reason stimulating. It is also believed that the sulfur in some cases at least may stimulate the legume organism and thus indirectly benefit the legume. The slight neutralizing effect of the oxidized sulfur has also been suggested as a cause for stimulation. This suggestion is given more credence since it has been found that many plants, and even the legumes, make better growth in a slightly acid culture solution. Whether the same condition is true in the field, especially for alfalfa, may be open to question.

But whatever may be the reason for the beneficial effect of the sulfur, only a reasonably rapid oxidation under field conditions is necessary or desirable. Even where sulfur may be needed to supply sulfate as plant-food, a sufficiently

rapid oxidation would occur with 40-mesh and the finer materials. Where leaching may occur very rapid oxidation may result in unnecessary loss of sulfate and perhaps other nutrients. A conservative recommendation is to use sulfur all of which passes a 40-mesh sieve. With the finer separates that would naturally be present, oxidation should occur sufficiently rapidly for soil use.

The system of farming, however, may have some bearing upon the degree of fineness advisable. Where very light applications are made annually, fine material should prove preferable. Where a heavier application is applied once in three or four years, coarser material would be preferable. Under such conditions, sulfur ground to pass a 10-mesh sieve would probably give satisfactory results. Only the crude sulfur would seem to be necessary in any case. Aside from the fact that the cost of crude sand sulfur is only about two-thirds that of the fine sulfur, the slow oxidation of the coarser particles should render it more effective through a period of three or four years. For immediate results, however, the finer the material the more effective it should prove.

TABLE 2

Acidity produced from sulfur treatments

	SULFUR MESH									
	100	80	60	40	20	10	Coarser than 10	Refined flour	Sand sulfur	Check
Lime requirement*.....	2,754	2,430	1,072	648	10	0	0	2,754	486	0
pH.....	5.5	5.5	6.1	6.4	6.6	6.9	7.0	5.9	6.6	7.0

* Pounds $CaCO_3$ per 2,000,000 pounds of soil.

ACIDITY PRODUCED

Since sulfur treatment produces acidity, soil 1 was studied to determine the change in active acidity and in the lime requirement. Table 2 shows that the lime requirement (1.2) was increased somewhat in proportion to the sulfur oxidized. The original soil was neutral. The other soils were similar in nature and practically neutral in reaction, and the effect of the sulfur on the reaction should be very similar to the results reported above. Sandy soils which are ordinarily low in both clay and organic matter exhibit very little buffer action, and have small capacity to neutralize acid unless carbonates or alkalinity is present. Consequently, a relatively small amount of oxidized sulfur, may change both the lime requirement and the hydrogen-ion concentration. Such a change would occur very soon after the application of fine sulfur, because of its very rapid oxidation. A continued extensive use of sulfur might produce an appreciable increase in both the lime requirement and the active acidity, and it is conceivable that on soils already slightly acid, the increased acidity might be harmful rather than beneficial. But as the

tendency of arid and semi-arid soils is toward alkalinity, the result would most probably be beneficial.

Since sulfuric is a strong and highly active acid, results common to acid soils, whether desirable or otherwise, will be very marked with a relatively small total sulfuric acidity. The acidity of inactive acid silicates and of easily oxidized and weaker organic acids is much less violent in its effect.

WATER-SOLUBLE CALCIUM

The amount of water-soluble calcium in previous work, some of which has not been published, has proved a rather sensitive indication of the amount of sulfur oxidized. The sulfuric acid produced brings calcium into solution very profusely. The results are shown in table 3 for soil 1 at the end of the experiment.

The large amount of water-soluble calcium might be one reason for the stimulation caused by sulfur on lime-loving plants. It is common knowledge that an application of limestone benefits legumes on sour soils, which are likely to be deficient in available calcium. Though the correction of the

TABLE 3

Water-soluble calcium in air-dry soil

	SULFUR MESH									
	100	80	60	40	20	10	Courser than 10	Refined flour	Crude sand	Check
Soluble calcium, *p.p.m.*.....	167	133	125	105	91	87	56	160	100	48

acidity to favor legume bacteria is usually suggested as the major reason for the response of legumes to lime, the supplying of available calcium doubtless is at times an important factor.

Since there is a marked increase in soluble calcium due to sulfur oxidation and subsequent solution, the application of sulfur temporarily functions indirectly to increase the supply of available calcium. This result will doubtless prove beneficial until a dangerously high degree of acidity results, as would seldom occur on soils responding to sulfur, or until the soil supply of calcium is detrimentally reduced by leaching. Where sulfur is used, therefore, it becomes important from the standpoint of calcium conservation, to adopt methods which will prevent unnecessary leaching.

CONCLUSIONS

1. The more finely sulfur is ground, the more rapidly it is oxidized. Sulfur ground to pass a 40-mesh sieve should contain enough fine material to satisfy the most urgent needs for soil use.

2. The oxidation of sulfur increases acidity or neutralizes alkalinity on alkaline soils.

3. The acid produced from the oxidized sulfur brings calcium into solution rather freely.

REFERENCES

(1) BURGESS, P. S. 1922 The reaction of soils in the field as influenced by the long-continued use of fertilized chemicals. *R. I. Agr. Exp. Sta. Bul.* 189: 9.

(2) JONES, C. H. 1913 Method of determining lime requirement of soils. *Amer. Fert.*, 39 (11): 28–29.

INDEX

Adsorption in soils, 192–194

Alicante, Marcos M. (paper), The Viability of the Nodule Bacteria of Legumes Outside of the Plant: I, II, 27–52.
(paper), The Viability of the Nodule Bacteria of Legumes Outside of the Plant: III, IV, V, 93–114

Alkali Soils—
Contribution to the Theory of the Origin of (paper), Alexius A. J. de'Sigmond, 455–479

Alumina, iron and silica, ratio of, in certain heavy clays, 349–359

Aluminum chlorides, effect of, on legume bacteria, 108

Amino nitrogen in soils and plants, 260, 265

Ammonia—
effect of, on cellulose decomposition, 116–126
in soils and plants, 263, 267

Ammonification—
effect of sulfur on, 248, 251
tests, measuring rate of urea decomposition by, 65–66

Ammonium sulfate, nitrification of, in presence of lime, 446–449

Anderson, J. Arlington (paper), The Influence of Available Nitrogen on the Fermentation of Cellulose in the Soil, 115–126

Arndt, C. H. (paper), The Salt Requirement of Lupinus Albus, 1–6

Austin, R. H., Spurway, C. H., and (paper), Some Residual Effects of Neutral Salt Treatments on the Soil Reaction, 71–74

Azotobacter chroococcum—
the endurance of other legume bacteria in the presence of, 47–50
thermal death point of, 100–101

Bacteria, pea, the endurance of, in the presence of *B. prodigiosus*, *B. capsulatus*, *B. subtilis*, *B. mesentericus*, pink yeast and molds, 47–49

Bacterial Flora,—
A Comparative Study of the, of Windblown Soil: I. Arroyo Bank Soil, Tucson, Arizona (paper), Laetitia Snow, 143–165

Bacterial types, the, occurring in frozen soil, 225–231

Barnette, R. Marlin (paper), Synthetic Calcium Silicates as a Source of Agricultural Lime: II. A Comparison of their Influence with that of other Forms of Lime upon Certain Microbiological Activities in the Soil, 443–453

Base exchange—
Colloidal behavior of soils and, 181–195

Baver, L. D. (paper), The Use of the Quinhydrone Electrode for Measuring the Hydrogen-Ion Concentration of Soils, 167–179

Bennett, H. H. (paper), Some Comparisons of the Properties of Humid-Tropical and Humid-Temperate American Soils; with Special Reference to Indicated Relations between Chemical Composition and Physical Properties, 349–375

Bouyoucos, George John (paper), Do Colloids Exist as a Coating around the Soil Grains? 481–487

Brown, S. M., Kelley, W. P. and (paper), Ion Exchange in Relation to Soil Acidity, 289–302.

Calcium—
determination of, in soil solution, 428, 431
effect of sulfur oxidation on water-soluble, in soils, 493

Calcium and Magnesium—
Influence of Form, Soil-Zone, and Fineness of Lime and Magnesia Incorporations Upon Outgo of (paper), W. H. MacIntire, 377–391

Calcium carbonate—
effect of, in soil on thermal death point of nodule bacteria, 103–104
effect of, on various nodule bacteria, 105–107
influence of, on solubility of phosphates, 435
influence of, on viability of nodule bacteria, 44–46

Calcium chloride, effect of, on soil reaction, 72–74
Calcium phosphate (tertiary)—
availability of phosphates from, 437–439
effect of, on various nodule bacteria, 105–108
effect of, on viability of nodule bacteria, 44–46
solubility of, as influenced by lime, 435
Calcium Silicates—
Synthetic, as a Source of Agricultural Lime: II. A. comparison of their influence with that of Other Forms of Lime upon Certain Microbiological Activities in the Soil (paper), R. Marlin Barnette, 443–453
Capillary forces versus centrifugal forces in determining the soil moisture content, 415–423
Carbon-nitrogen ratio, early knowledge on the subject of the, 115
Cecil clay, properties of, 373
Cellulose—
the influence of available nitrogen on the fermentation of, in the soil, 115–126
Coe, Dana G. (paper), Effects of Various Methods of applying Fertilizers on Crops and on Certain Soil Conditions, 7–21
(paper), The Effects of Various Methods of Applying Fertilizers on Crop Yields, 127–141.
Colloids—
Do, Exist as a Coating around the Soil Grains? (paper), George John Bouyoucos, 481–487
rôle of soil, in soil fertility, 181–182
Conductivity determinations of soil solution, 427–428.
Deuber, C. G. (paper), Potassium Ferrocyanide and Ferric Ferrocyanide as Sources of Iron for Plants, 23–26
Dialysis, preparation of soil extracts by, 426–427
Domontovitch, M. K., Prianishnikov, D. N., and (paper), The Problem of a Proper Nutrient Medium, 327–348
Donnan equilibrium, an application of the theory of, to soils, 439
Duley, F. L. and Jones, M. M., (paper), Effects of Soil Treatments Upon the Draft of Plows, 277–288
Duley, F. L., (paper), The Loss of Soluble Salts in Runoff Water, 401–409
Erosion, relation of, to loss of soluble salts, 401–409
Fertilizers—
effect of, on replacement of cations in soils, 188
Effects of Various Methods of Applying, on Crops and on Certain Soil Conditions (paper), Dana G. Coe, 7–21
The Effects of Various Methods of Applying, on Crop Yields, (paper), Dana G. Coe, 127–141
Fife, J. M., (paper), The Effect of Sulfur on the Microflora of the Soil, 245–252
Flax as influenced by nitrogenous fertilizers, 303–306
Garbage tankage, the availability of nitrogen in, and in urea in comparison with standard materials, 59–69
Harper, Horace J., Thomas, Royle, P., and (paper), The Use of Oat Straw in a System of Soil Fertility, 393–400.
Harris, Karl, Moyer, Thomas, D., and (paper), The Moisture Equivalent of Soils, 411–424.
Heat of wetting, study of colloids by the method of, 481–482
Humus, presence of, in alkali soils, 462–466
Hydrochloric acid, effect of, on legume bacteria, 108
Hydrogen-ion concentration—
effect of plant growth on reaction of culture solution, 4–5
its effect on plant growth, 24–25
of soil water extracts, 184–185
the influence of, on legume bacteria, 108
The Use of the Quinhydrone Electrode for Measuring the, of Soils, (paper), L. D. Baver, 167–179
variations in, in various soil horizons, 72–74
Iron—
Potassium Ferrocyanide and Ferric Ferrocyanide as Sources of, for Plants, (paper), C. G. Deuber, 23–26
Joffe, J. S., and McLean, H. C., (paper), Colloidal Behavior of Soils and Soil Fertility: II. The Soil Complex Capable of Base Exchange and Soil Acidity, 181–195
Johnston, William W., (paper), The Production and Use of Sulfate in Humid and

Arid Soils as Affected by Cropping and Sulfur Treatment, 233–244
Jones, M. M., Duley, F. L., and (paper), Effects of Soil Treatments Upon the Draft of Plows, 277–288
Kelley, W. P. and Brown, S. M., (paper), Ion Exchange in Relation to Soil Acidity, 289–302.
Krassovsky, Irene (paper), Physiological Activity of the Seminal and Nodal Roots of Crop Plants, 307–325
Legume bacteria, influence of various acids on, 108
Legume Nitrogen—
The Form of, Assimilated by Non-legumes when Grown in Association (paper), James Henry Stallings, 253–276
Lime—
calcium silicate as a source of, 443–451
factors influencing the effects of, additions, 377
influence of, upon bacterial numbers of soil, 443–449
influence of, upon sulfate formation, 449–451
influence of various forms of, on nitrate formation, 445–451
the influence of, and phosphatic fertilizers on the phosphorus content of the soil solution and of soil extracts, 425–441
Lochhead, A. G., (paper), The Bacterial Types Occurring in Frozen Soil, 225–231
Lupinus Albus—
the salt requirements of, 1–6
MacIntire, W. H. (paper), Influence of Form, Soil-Zone, and Fineness of Lime and Magnesia Incorporations upon Outgo of Calcium and Magnesium, 377–391
McLean, H. C., Joffe, J. S. and (paper), Colloidal Behavior of Soils and Soil Fertility: II. The Soil Complex Capable of Base Exchange and Soil Acidity, 181–195
Magnesium chloride, effect of, on soil reaction, 72–74
Manure—
effect of, on draft of plow, 278
Moisture,—
A Study of Some of the Factors Affecting the Supply of, to Crops in Sandy Soils, (paper), H. W. Stewart, 197–223
equivalent of soils, 411–424
Moyer, Thomas D., and Harris, Karl, (paper), The Moisture Equivalent of Soils, 411–424
Nitrates—
accumulation of, in Carrington loan when straw was applied, 396
effect of, on cellulose decomposition, 116–126
influence of various forms of lime on formation of, 445–449
in soils, tops and roots of plants, 259, 264
Nitric acid—
effect of, on legume bacteria, 108
Nitrification—
as affected by cellulose, 121–124
influence of sulfur on, 249, 251
of $(NH_4)_2SO_4$ in presence of lime, 446
Nitrites in soil and plants, 263
Nitrogen—
The Availability of, in Garbage Tankage and in Urea in Comparison with Standard Materials (paper), A. L. Prince and H. W. Winsor, 59–69
The Effect of Varying the, Supply on the Ratios between the Tops and Roots in Flax (paper), Thomas W. Turner, 303–306
The Influence of Available, on the Fermentation of Cellulose in the Soil, (paper), J. Arlington Anderson, 115–126.
Nodal roots, physiological activity of, 307–321
Nodule Bacteria—
Review of literature on viability of, 27–28
The Viability of the, of Legumes, Outside of the Plant: I, II, (paper), Marcos M. Alicante, 27–52
The Viability of the, of Legumes Outside of the Plant: III, IV, V, (paper) Marcos Mondejar Alicante, 93–114
Nutrient medium—
The Problem of a Proper, (paper), D. N. Prianishnikov, and M. K. Domontovitch, 327–348
Organic matter, method for determining, in soil, 460–461
Parker, F. W., and Tidmore, J. W. (paper), The influence of Lime and Phosphatic Fertilizers on the Phosphorus Content of the Soil Solution and of Soil Extracts, 425–441
Phosphatic fertilizers—
the influence of lime and, on the phos-

phorus content of the soil solution and of soil extracts, 425–444
Phosphorus—
determination of, in soil solution, 428–435
Plant extract, method of obtaining, 256
Plowing, methods of determining draft in, 277
Potassium chloride, effect of, on soil reaction, 72–74
Powell, E. B., (paper), A New Soil Core Sampler, 53–57
Prianishnikov, D. N., and Domontovitch, M. K., (paper), The Problem of a Proper Nutrient Medium, 327–348
Prince, A. L., and Winsor, H. W., (paper), The Availability of Nitrogen in Garbage Tankage and in Urea in Comparison with Standard Materials, 59–69
Protozoa, development of, in frozen soils, 226
Quinhydrone electrode, the use of the, for measuring the hydrogen-ion concentration of soils, 169–179
Radiobacter, the endurance of cowpeas, soybean and sweet clover organisms in the presence of, 47–48
Radicicola—
effect of oxygen supply on the growth of, 94–96
effect of shaking on, 96
thermal death point of, 100–101
Roots—
Physiological Activity of the Seminal and Nodal, of Crop Plants, (paper), Irene Krassovsky, 307–325
Salts—
the loss of soluble, in runoff water, 401–409
Seminal roots, physiological activity of, 307–321
Sigmond, Alexius A. J. de', (paper), Contribution to the Theory of the Origin of Alkali Soils, 455–479
Snow, Laetitia M., (paper), A Comparative Study of the Bacterial Flora of Windblown Soil: I. Arroyo Bank Soil, Tucson, Arizona, 143–165
Sodium—
carbonate, rôle of, in alkali soils, 467
chloride, effect of, on soil reaction, 72–74
Soil—
a comparative study of the bacterial flora of windblown,: I. Arroyo Bank Soil, Tucson, Arizona, 143–165
A New, Core Sampler, (paper), E. B. Powell, 53–57
a study of the, complex capable of base exchange, 181–194
Effects of, Treatments upon the Draft of Plows (paper), F. L. Duley and M. M. Jones, 277–288
fluctuation of, horizons, 458
grains, presence of colloid coatings around, 481–486
influence of lime upon microbiological activities in the, 443–452
method of determining organic matter in, 460–461
The Bacterial Types Occurring in Frozen, (paper), A. G. Lochhead, 225–231
the effect of sulfur on the microflora of, 245–252
Soil Acidity—
effect of, upon the infecting power of B. radicicola, 104–105
Ion Exchange in Relation to, (paper), W. P. Kelley and S. M. Brown, 289–302
problem of, 182–183
quantitative determination of, 186
the soil complex capable of base exchange and, 181–195
Soil Conditions—
effects of various methods of applying fertilizers on crops and on certain, 7–21
peculiar form of, in Central America, 359
Soil Fertility—
Colloidal Behavior of Soils and, II. The Soil Complex Capable of Base Exchange and Soil Acidity, (paper), J. S. Joffe, and H. C. McLean, 181–195.
The Use of Oat Straw in a System of, (paper), Royal P. Thomas and Horace J. Harper, 393–400
Soil horizons, variation in reaction in different, 72–74
Soil infusion, effect of, on survival of nodule bacteria, 30–38
Soil moisture, effect of, on draft of plow, 282–287
Soil Reaction—
Some Residual Effects of Neutral Salt Treatments on the, (paper), C. H. Spurway and R. H. Austin, 71–74
variation in, when water extract or neutral salt solution extract is used, 184

Salt Requirements—
The, of Lupinus Albus, (paper), C. H. Arndt, 1–6
Soil Solution—
calcium content of, 428–434
conductivity determinations on, 427–428
dialysis of, 426–427
phosphorus content of, 428–439
The Influence of Lime and Phosphatic Fertilizers on the Phosphorus Content of the, and of Soil Extracts (paper), F. W. Parker and J. W. Tidmore, 425–441
Soils—
adsorption phenomena in, 192–194
colloidal behavior of, and soil fertility, 181–195
factors, affecting the moisture supply in sandy, 197–217
properties of Central American, 351–359
Some Comparisons of the Properties of Humid-Tropical and Humid Temperate American; With Special Reference to Indicated Relations between Chemical Composition and Physical Properties (paper), H. H. Bennett, 349–375
The Moisture Equivalent of, (paper), Moyer D. Thomas, and Karl Harris, 411–424
use of different grades of sulfur in, 489–493
Spurway, C. H., and Austin, R. H. (paper), Some Residual Effects of Neutral Salt Treatments on the Soil Reaction, 71–74
Stallings, James Henry (paper), the Form of Legume Nitrogen Assimilated by Non-legumes when Grown in Association, 253–276
Stephenson, R. E., (paper), Relation of Fineness of Grinding to Rate of Sulfur Oxidation in Soils, 489–494
Stewart, H. W., (paper), A Study of Some of the Factors Affecting the Supply of Moisture to Crops in Sandy Soils, 197–223
Straw, the use of, in a system of soil fertility, 393–399
Sulfate—
The Production and Use of, in Humid and Arid Soils as Affected by Cropping and Sulfur Treatments, (paper), William W. Johnston, 233–244
Sulfur—
effect of, applications to soil and sulfur content of crops, 235–238
review of literature on, in agriculture, 233
The Effect of, on the Microflora of the Soil, (paper), J. M. Fife, 245–252
use of different grades of fineness of, in soils, 489–493
Sulfuric acid, effect of, on legume bacteria, 108
Sulfur Oxidation—
Relation of Fineness of Grinding to Rate of, in Soils, (paper), R. E. Stephenson, 489–494
Sulfur treatments, the production and use of sulfate in humid and arid soils as affected by cropping and, 233–244
Thomas, Royle P., and Harper, Horace J. (paper), The Use of Oat Straw in a System of Soil Fertility, 393–400
Tidmore, J. W., Parker, F. W., and (paper), The Influence of Lime and Phosphatic Fertilizers on the Phosphorus Content of the Soil Solution and of Soil Extracts, 425–441
Transpiration coefficient, calculation of, 76
Tulaikov, N. M., (paper), The Utilization of Water by Plants Under Field and Greenhouse Conditions, 75–91
Turner, Thomas W. (paper), The Effect of Varying the Nitrogen Supply on the Ratios between the Tops and Roots in Flax, 303–306
Urea—
the availability of nitrogen in garbage tankage and in, in comparison with standard material, 59–69
Water—
The Loss of Soluble Salts in Runoff, (paper), F. L. Duley, 401–409
The Utilization of, by Plants Under Field and Greenhouse, Conditions, (paper), N. M. Tulaikov, 75–91
Weathering, peculiar types of, 359–361
Winsor, H. W., Prince, A. L. and (paper), The Availability of Nitrogen in Garbage Tankage and in Urea in Comparison with Standard Materials, 59–69
Zeolites in soils, 181–182, 466–467

FOR THE MEASUREMENT OF COHESION IN COLLOIDAL SOILS

The Cenco Tenacity of Soils Apparatus Has Been Found Very Satisfactory

No. 12430..$17.50

A complete description of the apparatus and its method of use for this purpose will be found in an article by F. Hardy, M.A., of the Imperial College of Tropical Agriculture, Trinidad, British West Indies, in the Journal of Agricultural Science, Vol. XV, Part IV, for October, 1925, pages 420 et seq., entitled, "Cohesion in Colloidal Soils."

CENTRAL SCIENTIFIC COMPANY
LABORATORY Apparatus CENCO Chemicals SUPPLIES
460 E. Ohio St., Chicago, U.S.A.

ENGRAVINGS FOR MEDICAL AND SCIENTIFIC PUBLICATIONS

MANY years experience working in co-operation with publishers and authors, engaged in the scientific field, have admirably fitted us for this exacting work. Our clientele includes, among many others, the scientists of the Johns Hopkins University. Such widely diversified subjects as Biology, Mineralogy, Physics, Medicine, Surgery, Zoölogy, Mathematics, etc., etc., are constantly requiring our services, in the matter of engraving reproductions.

Naturally, we have developed an intimate knowledge of the requirements of this particular phase of the photo-engraving industry. We understand the particular illustrative points that must be emphasized. We are accustomed to working, moreover, from written instructions, since our clients are frequently out of direct touch with us, or at distant points.

That we have been eminently successful is attested by even our most critical patrons, whom we continue to serve after many years of patronage.

We will be glad to submit samples, make estimates and co-operate, in every possible way, in the production of YOUR work.

BALTIMORE-MARYLAND
ENGRAVING COMPANY

BALTIMORE, MARYLAND

(In writing to advertisers, please mention the journal—it helps.)

DIRECTORY OF FERTILIZER MANUFACTURERS AND DEALERS

The American Agricultural Chemical Co.

2 RECTOR STREET

Cable Address: Agrichem New York City

Steacy & Wilton Company

Manufacturers of

"Sterling" Brand Hydrated Lime

WRIGHTSV LLE PENNA.

The Determination of Hydrogen Ions

Wm. Mansfield Clark, Ph.D.
U. S. Hygienic Laboratory, Public Health Service

Recognized as the authoritative text book on hydrogen ion work. Discusses the fundamental theories involved as well as practical applications A comprehensive bibliography is a feature.

Price, $5.00

THE WILLIAMS & WILKINS COMPANY
Publishers of Scientific Books and Periodicals
BALTIMORE, MARYLAND

CHARLES WARNER COMPANY

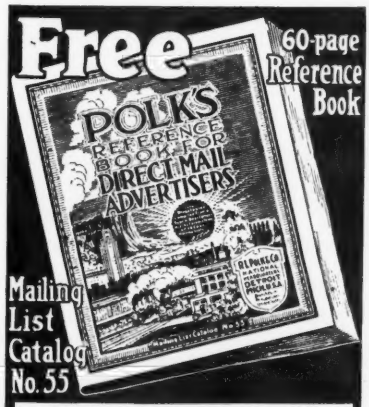
Manufacturers of Warner's

"LIMOID"

(Pure "Cedar Hollow" Hydrated Lime)

ALSO FINELY PULVERIZED LIMESTONE

Wilm'n, Del. Philada., Pa. N. Y. City



POLK'S REFERENCE BOOK
FOR DIRECT MAIL ADVERTISERS

Shows how to increase your business by the use of Direct Mail Advertising. 60 pages full of vital business facts and figures. Who, where and how many prospects you have. Over 8,000 lines of business covered.

Write for your FREE copy.

R. L. POLK & CO., Detroit, Mich.
400 POLK DIRECTORY BUILDING
Branches in principal cities of U. S.

"SCIENTIFIC AGRICULTURE"

The only monthly magazine published in Canada which deals exclusively with agricultural research, extension, education, experimentation, etc.

Those who wish to keep in touch with the work of professional agriculturists in Canada should subscribe to this journal, which is now in its sixth volume.

"Scientific Agriculture" is owned, edited and published by the Canadian Society of Technical Agriculturists, which was organized at Ottawa in 1920 and already has over 900 members.

One volume is issued each year. Each issue contains about 48 pages.

Price $2.00 per year
SOLD ONLY BY THE PUBLISHERS.

THE CANADIAN SOCIETY OF TECHNICAL AGRICULTURISTS
P. O. Box 625, Ottawa, Canada.

(In writing to advertisers, please mention the journal—it helps.)

DIGEST OF AMERICAN AGRICULTURE

Reaching the Vast Purchasing Power of the 100,000,000 Russian Ukrainian and Siberian FARMERS Through County Agents, Agricultural Colleges and Experiment Stations, Co-operative Organizations, State Purchasing Agencies, Department of Agriculture in U. S. S. R.

EDITED BY
D. N. BORODIN

A Journal Devoted to Americanization of Russian Agriculture. Widely Circulated in the Union of Socialist Soviet Republics. An Important Advertising Medium for Those Interested in the Russian Market. Advertisements Translated Free of Charge.

RATES ON APPLICATION

Published By

RUSSIAN AGRICULTURAL AGENCY IN AMERICA

Inc.

136 Liberty Street, New York, N. Y., U. S. A.

Fundamental Concepts of Physics

By PAUL R. HEYL, PH.D.
Physicist, Bureau of Standards, Washington, D. C.

No man can reduce the abstractions of physics, of space, matter and time, of atomic structure, of thermodynamics, to the language of the primer; but Dr. Heyl's book brings them within the scope of any person willing to think.

Dr. Heyl was winner of the Boyden premium of the Franklin Institute in 1907 offered to that scientist who should measure the velocity of the invisable light rays; he is well known for his work in crystallization, under electrostatic stress, from a current bearing electrolyte.

A book which will serve a dual purpose—to entertain and to instruct. A book which you will enjoy reading just as you like good literature of other sorts.

Price $2.00

THE WILLIAMS & WILKINS COMPANY
Publishers of Scientific Books and Periodicals
BALTIMORE, U. S. A.

(In writing to advertisers, please mention the journal—it helps.)

More Nitrogen Is Needed---

IN a speech before the recent international gathering of fertilizer men at Biarritz, France, Dr. Bueb, the head of the great German Nitrogen Syndicate, said:

> "The increase in the yield of agricultural products is essentially obtained from the nitrogen applied, provided that at least enough phosphoric acid and potash is present to enable the nitrogen to produce its full effect."

Dr. Andrew H. Soule, President of Georgia State College of Agriculture, in a recent article says:

> "In tests made at strategic points throughout the state of Georgia during the past decade, it has been found that a complete fertilizer, or a formula containing a generous amount of readily available nitrogen, phosphoric acid, and potash has proved the most profitable to use with cotton. While the application of a complete fertilizer did not seem to be quite so important in the case of corn, nitrogen still proved to be the element most needed on practically all the types of soil studied. This was also true of oats and other winter-growing cereals. * * * Since the experiments were conducted on the principal soil types of the state, the results would seem to be capable of general application throughout that great stretch of territory extending from Maryland to Texas and embracing what is known as the Piedmont and Coastal Plain areas. These field trials confirm our opinion relative to the importance of using nitrogen in a much more generous manner than has obtained in the past. At least 30 to 40 pounds per acre should be used under our principal farm crops. Doubling and trebling the amount of the high-grade formulas now recommended for general use will therefore prove a profitable procedure to follow. Where we previously used 2 to 3 per cent of nitrogen, we now need to apply 4 to 5 per cent."

Most of the nitrogen in Dr. Soule's tests was from Sulphate of Ammonia. There is no better carrier of nitrogen than this, our own home product.

Write for our bulletins on nitrogen supply

The Barrett Company
Agricultural Department
New York, N. Y.

Medina, Ohio — Atlanta, Georgia — Berkeley, Calif.

ARCADIAN *Sulphate of Ammonia*

Chilean Nitrate of Soda

The Fertilizer that furnishes Nitrogen in the immediately available form

Twenty Years' investigations at the New Jersey Experiment Station showed that "The percentage of Nitrogen recovered in the Crop was greater with the Nitrate than with any of the other materials," the 20-year average being as follows:

Nitrate of Soda	62.42%	Dried Blood	38.69%
Sulphate of Ammonia	47.48%	Cow Manure	32.69%

Dr. G. Smets, Liege, Belgium, gives the relative values of Nitrogen from different sources as follows:

Nitrate of Soda	100%	Dried Blood	65%
Sulphate of Ammonia	75%	Fish Scrap, etc	60%
Cyanamid	69%	Farmyard Manure	40%

For reliable information write

DR. WM. S. MYERS

CHILEAN NITRATE OF SODA EDUCATIONAL BUREAU

25 Madison Ave., New York